EFFECT OF VEGETATION COMPOSITION AND HUNTING ON HABITAT SELECTION BY FERAL GOATS

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Isolated Hill Scenic Reserve, May 1996 (Photograph, K. Nicolle)

"Historically, the goat has been the subject of total mismanagement by humans and is consequently the victim of considerable prejudice and ill-founded perceptions due to a complete lack of knowledge of the animal, management techniques and the industry in general."
(Toseland, 1993, *in:* Freudenberger, D. (Ed.) 1993. *Feral goat management: planning for action.* Proceedings of the National Workshop, Dubbo, 9-11 October 1992, Bureau of Resource Sciences. 106p.).

Pair of feral goat kids, Waima River, August 1995 (Photograph, H.Cochrane)

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Abstract

Feral goats are a continuing threat to conservation values in New Zealand. First introduced in 1773 feral goats have spread to occupy many areas of public conservation land. Organised control of feral goats by private landholders began in the early 1900s, but it was not until the mid 1930s that organised government control began. From the 1960s onwards substantial changes are evident in the philosophy governing the control of introduced herbivores in New Zealand, changes that have marked a move away from emphasising the pests *per se* to focusing upon the resource under threat.

Isolated Hill Scenic Reserve is located in Southern Marlborough, South Island, New Zealand. The reserve is approximately 2 800 ha in size and is one of the largest remaining forest remnant areas in Southern Marlborough. Feral goats have been present in the reserve since the early 1900s, and are considered a threat to indigenous flora and fauna within the reserve.

Eleven different vegetation communities were identified at Isolated Hill Scenic Reserve and five at Black Angel Creek. Communities were defined using three multivariate techniques: agglomerative clustering, TWINSPAN, and detrended correspondence analysis. Diversity indices (taxonomic species diversity, Berger-Parker dominance index, and Margalef's diversity index) were calculated for each of the identified communities. A vegetation map of Isolated Hill Scenic Reserve was produced (using aerial photographs and ground-surveys) to show the extent and coverage of vegetation communities in the reserve.

Feral goat habitat selection was recorded at Isolated Hill Scenic Reserve and Black Angel Creek from November 1994 through July 1997. Habitat selection was measured using two different techniques: direct observation and faecal pellet group density. Feral goats differentially selected habitats at both Isolated Hill Scenic Reserve and Black Angel Creek. Vegetation communities that were selected most often were broadleaf,

mahoe-titoki, and grass/scrubland at Isolated Hill Scenic Reserve, and scrub/grassland and grassland at Black Angel Creek. In November 1996 a major control operation against feral goats was launched within the reserve. No significant differences were observed pre and post-control at Isolated Hill Scenic Reserve or Black Angel Creek using direct observation. However faecal pellet densities did reveal a significant change in habitat selection post-control ($P < 0.001$). Feral goats selected habitats that provided greater cover. No significant differences were observed for seasonal use of habitat. Habitat relationships were modelled using correlation, multiple regression, and a habitat suitability index based upon diet preferences. Correlation with habitat variables was non-significant. Four-variable multiple regression models were able to predict feral goat habitat selection successfully (range of r^2 values 0.91 – 0.99) for seasons, pre and post-control, and overall habitat selection. Variables that were important in models included *Griselinia littoralis* cover, *Nothofagus* cover, and total palatable plant species cover. Variables that were not often used in models included hunting difficulty and an index of vegetative cover. Habitat suitability index models based solely on diet were not significant predictors of feral goat habitat selection.

Management of feral goats at Isolated Hill Scenic Reserve was also investigated. Similarity exists between the distribution of kill locations and observed pellet group densities but not with direct observation of feral goats at Isolated Hill Scenic Reserve. Habitats that were easiest to hunt were grassland or subalpine vegetation and the perceived hunting difficulty was correlated with distribution of kills. Depending on the category of hunter their effectiveness varied significantly. By incorporating habitat selection and use models into operational control programmes greater efficacy of control programmes may be achieved.

Chapter 1 - Introduction

"Opossums, deer and goats are destroying huge tracts of native forest which only a doubling of the conservation budget can reverse, says the Royal Forest and Bird Protection Society."
The New Zealand Herald, pg. 14, December 1, 1994

"But it's the goats or the bush - you can't have both .....it is very hard to determine how many goats are in any particular area...."
The New Zealand Herald, S3 pg1, January 3 1996

"The first rule of applied ecology goes: if at first you don't succeed you have misunderstood the dynamics of the system."
Graeme Caughley, 1989, pg6

1.1 Feral goats: arch despoilers of the earth

Feral goats (*Capra hircus* L.) have a well-documented history of impacts at the global scale on both conservation and non-conservation lands (Furon, 1954; Ball, 1974; Coblentz, 1978; Bullock 1985; Daly and Goriup, 1987; Freudenberger, 1993; Keegan *et al.*, 1994). This history is also apparent in New Zealand where goats were first introduced in 1773 (Table 1.1), and were subsequently reintroduced and allowed to expand in range until the mid 1980s. Feral goats have had considerable impact in many areas (Thomson, 1922; Moore and Cranwell, 1934; Turbott, 1948; Atkinson, 1964; Williamson, 1975; Campbell and Rudge, 1984; Hayward, 1985; New Zealand Association of Soil Conservators, 1985; Mitchell *et al.* 1987; Jacobs, 1990; de Lange, 1990; Cochrane, 1994; Department of Conservation, 1998).

Impacts can be broadly divided into three areas:

1) direct impacts through herbivory;
2) indirect impacts through synergistic effects with other biotic factors such as unpalatable or exotic plant species, which long term can lead to compositional changes (Jacobs, 1990; Brockie, 1992);

3) indirect impacts through synergistic effects with abiotic factors such as wind (Campbell and Rudge, 1984) which long term can lead to increased rates of erosion (New Zealand Association of Soil Conservators, 1985).

Table 1.1 Introductions of goats to New Zealand (from Thomson, 1922; Wodzicki, 1950). Range increased during the mid 1980s subsequent to the marked decline in the commercial value of fibre from goats.

Year	No.	Destination	Importer
1773	2	Queen Charlotte Sound	Capt. J Cook
1777	2	Queen Charlotte Sound	Capt. J. Cook
1850	?	Enderby Island	Capt. Enderby
1865	4	Auckland and Enderby Islands	Capt. Norman
1867	3	Canterbury (Cashmere goats)	Canterbury Society
1867	4	Otago (Angora goats)	Otago Society
1869	?	Auckland (Angora goats)	Auckland Society
1876	120	Port Hills (Angora goats)	Melbourne Acclimatisation Society
1850-1980s	?	Range expansion within New Zealand	Primarily internal expansion although later (especially early 1980s) high value animals were imported for bloodstock

Feral goats continue to threaten biodiversity values in New Zealand on both conservation and non-conservation land (Department of Conservation, 1998), despite considerable expenditure on control. Why is this? What is it about feral goats and other feral and wild introduced mammals in New Zealand that continues to make them a problem? Could it be that we have indeed misunderstood the dynamics of the feral goat vegetation system.

1.2 The history of animal management in New Zealand

Currently, New Zealand has 23 feral or wild introduced mammalian herbivores (Table 1.2) that are considered to reduce conservation values on conservation land in New Zealand. These 23 pest species are a legacy of a long period of introductions that began in 1773.

Prior to 1773 only two mammals (kiore (*Rattus exulans*) and kuri (*Canis familiaris*)) had been introduced to New Zealand (King, 1990), neither of which were herbivores. Captain James Cook is credited with the first recorded release by a European of a herbivore onto the shores of New Zealand (Table 1.1); on 2 June 1773, a party from his ship released one male and one female goat on the eastern side of Queen Charlotte

Sound (Thomson, 1922). Two sheep from the Cape of Good Hope were also released, however both were found dead shortly after release. On his third trip to New Zealand, in 1777, Cook released another pair of goats and in addition two pigs (Thomson, 1922).

The introduction of mammalian herbivores in New Zealand must be considered in the light of the paradigm that existed at the time; after all the introductions reflect the society of the period. Similarly, management during this century should be considered alongside the society of the time. Hence this review has been separated into four categories that reflect the overriding paradigm of that period.

Table 1.2 Currently extant introduced feral and wild mammalian herbivores in New Zealand (Thomson, 1922; King, 1990).

Species	Current distribution	Year of Introduction
Family: Macropodidae		
Macropus eugenii (Dama wallaby)	Kawau and Nth Isl – localised	~ 1870
M. rufogriseus (Bennet's wallaby)	Sth Isl – localised	Liberated 1874
M. parma (Parma wallaby)	Kawau Isl	~ 1870
Petrogale penicillata (Brushtail rock wallaby)	Kawau, Motutapu, Rangitoto Isl.	1873
Wallabia bicolor (Swamp wallaby)	Kawau Isl.	~ 1870
Family: Phalangeridae		
Trichosurus vulpecula (Brushtail possum)	Widespread	1858 onwards
Family: Lagomorpha		
Oryctolagus cuniculus (European rabbit)	Widespread	1777
Lepus europaeus (Brown hare)	Widespread	1851 Onwards
Family: Equidae		
Equus caballus (Feral horse)	Localised	1814
Family: Suidae		
Sus scrofa (Feral pig)	Widespread	1769
Family: Bovidae		
Bos taurus (Feral cattle)	Localised	1814
Rupicapra rupicapra (Chamois)	Sth Isl.	1907
Hemitragus jemlahicus (Thar)	Sth Isl.	1904
Capra hircus (Feral goat)	Widespread	1773, 1777
Ovis aries (Feral sheep)	Localised	~1820s
Family: Cervidae		
Cervus elaphus scoticus (Red deer)	Widespread	1850s, 1861
C. elaphus nelsoni (Wapiti)	Localised, Fiordland	1870s, 1905
C. nippon (Sika deer)	North Isl.	1885, 1905
C. timorensis (Rusa deer)	Localised, Nth Isl.	1907
C. unicolor (Sambar)	Localised, Nth Isl.	1875
Dama dama (Fallow deer)	Localised, Nth & Sth Isl.	1860s
Odocoileus virginianus (Whitetail deer)	Localised	1905

1.2.1 The introduction of animals to New Zealand – larder stocking (1773-1860)

Cook was credited as the first European to introduce mammals to New Zealand (Thomson, 1922). The primary reason for the initial release of both goats, pigs, and

sheep was to provide a potential food source for ship-wrecked mariners on both mainland New Zealand and its offshore islands (see Table 1.1, the releases by Enderby and Norman) and to provide a potential food supply for early settlers (Thomson, 1922; Wodzicki, 1950). Later goats were utilised for their commercial value (meat, fibre, and milk) and their value for weed control. Generally, during the 1850s and 1860s with increased settlement of New Zealand lesser consideration was given to food sources and more to pets and potential sporting resources (Thomson, 1922). Approximately 39% of currently extant mammalian herbivores were introduced during this period.

1.2.2 The period of acclimatisation (1861-1910)

The acclimatisation period was characterised by the introduction of many of the species that are pests today. It is a period that is also marked by the emergence of Acts of Parliament that sought to protect and promote introduced animals.

Wodzicki (1950) stated that by the 1860s settlement of New Zealand was considered advanced enough for settlers to divert themselves away from a constant need to secure food. Consideration was given to sentiment and sport values for introduced animals, although utility was also a concern (the release of possums was initially done to establish a fur industry although other reasons emerged later (see Table 1.3 for a full history of the introduction of possums)). Wodzicki (1950) also noted that many people believed that the native flora and fauna would disappear and therefore needed to be replaced with a flora and fauna resembling that of Europe.

In 1861 the first legislative act to address the introduction of animals to New Zealand was passed (McKinnon and Coughlan, 1963). The Protection of Certain Animals Act 1861 had as its intention to:

"encourage the importation of animals not native to New Zealand which would contribute to the pleasure and profit of the inhabitants, when they became acclimatised and were spread over the country in sufficient numbers." (Wodzicki, 1950, pg. 6)

This Act gave complete protection to all introduced game animals until the passing of the Protection of Animals Act 1867 which prescribed detailed schedules for specific game animals, including deer, hares and antelope, and gave legal standing to the rules of the newly formed acclimatisation societies in New Zealand. The Nelson

Acclimatisation Society was formed in 1863 (Fig. 1.1), which marked the beginning of organised management of introduced mammal (Galbreath, 1993). At a government level the Colonial Secretary's Office (Fig. 1.1) was involved in introduced mammal management at a similar time.

In 1873 a complete revision of the earlier acts, the Protection of Animals Act 1873, again addressed definitions for various groups of animals in New Zealand. Again the role of acclimatisation societies was reinforced in particular with reference to management of game species in regional areas (McKinnon and Coughlan, 1963). Administratively the State Forests Department (later the Department of Lands and Survey) was also involved in managing state forests at this time (McKinnon and Coughlan, 1963).

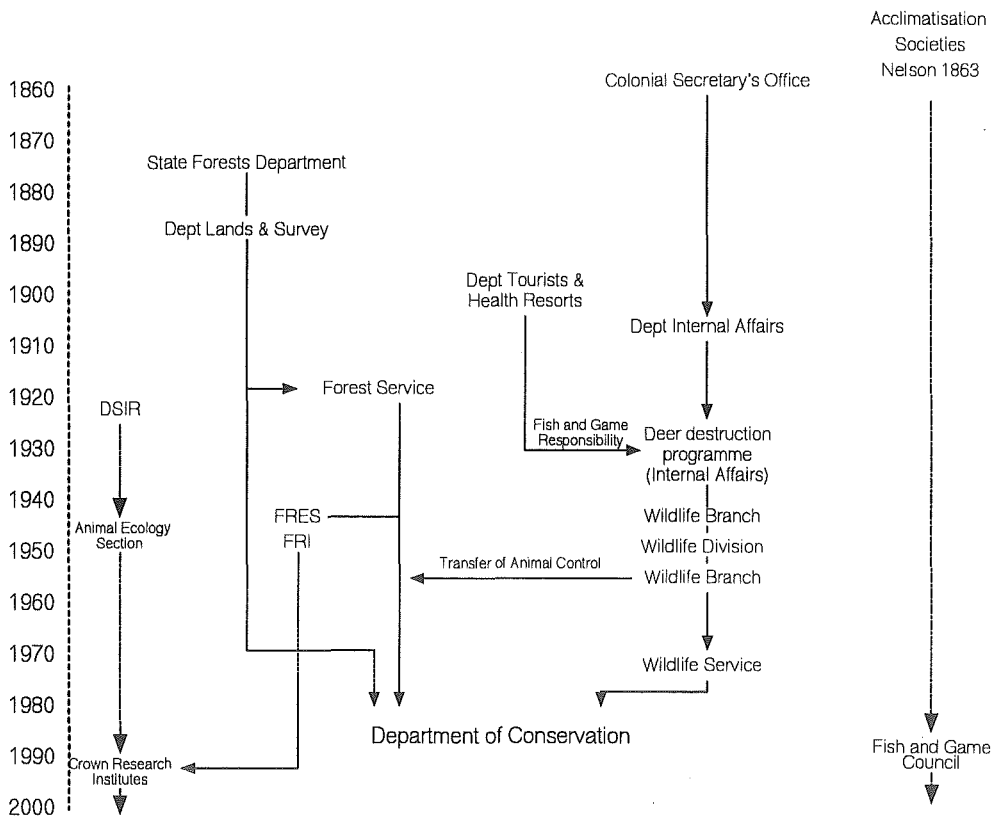


Figure 1.1 Schematic diagram of the changes in the structure of administrative bodies responsible or involved in the control and management of introduced mammalian herbivores in New Zealand 1863-1992. The focus is on administration of indigenous forested lands, and only one non-governmental organisation is included (Acclimatisation Societies/Fish and game Council). FRES refers to the forest and range experiment station, and FRI to Forest Research Institute. The Department of Conservation is the current governmental body in charge of the administration and management of conservation lands.

The Animals Protection Amendment Act 1895 addressed the question of importation of exotic fauna to New Zealand. This legislation prohibited importation of any form of game or animal without the written consent of the Minister of Agriculture. Further, it was made clear that vessels docking in New Zealand were required to take precautions to ensure that no exotic fauna landed inadvertently (McKinnon and Coughlan, 1963). This legislation received only minor amendments until the Animals Protection Amendment Act 1920 was passed. The primary reason for this amendment was to formally give the possum legislative protection regulating when and where it could be killed (McKinnon and Coughlan, 1963).

Table 1.3 Importation of the Brushtail possum (*Trichosurus vulpecula*) to New Zealand (Pracy, 1974). Importation occurred initially for utilitarian reasons, but later a number of animals were imported as pets.

Year	Origin	No.	Colour	Destination	Importer
1837-1840	Tasmania	?	Black	Riverton	Capt. J. Howell
1858	Tasmania	?	Black	Riverton	C. Basstian
1865	Australia	42	?	Banks Peninsula	Canterbury Acclimatisation Soc.
1868	Australia	2	Grey	Wanganui	Wanganui Acc. Soc.
1868	Australia	?	Grey	Motutapu Island	Sir George Grey
1869	Australia	?	Grey	Kawau Island	Sir George Grey
1870	Australia	?	Grey	Wairoa River	Auckland Acc. Soc.
1870	?	?	?	Southland	Capt. Ellis
1872	Australia	?	Grey	Wairarapa	Abbot
1875	Australia	5	Grey	Waiwera	Auckland Acc. Soc.
1890	Australia	8	Grey	Dunedin	Otago Acc. Soc.
1891	Australia	?	Grey	Blue Mountains	Otago Acc. Soc.
1892	Tasmania	19	Black	Paraparaumu	Wellington Acc. Soc
1894	Australia	12	Grey	Catlins District	Otago Acc. Soc.
1895	Australia	12	Grey	Catlins District	Otago Acc. Soc.
1898	Tasmania	2	Black	Westland	R.J. Seddon
1898	Tasmania	2	Black	Government House, Wgtn	N.Z. Government (Cabinet req.)
1898	Tasmania	6	Black	Buckland Range, Buller	Buller Acc. Soc.
1898	Tasmania	4	Black	Westland	Westland Acc. Soc.
1898	Tasmania	4	Black	Westland	Grey Acc. Soc.
1898	Tasmania	8	Black	Loopline Road	Buller Acc. Soc.
1898	Tasmania	8	Black	Westland	Grey Acc. Soc.
1898	Tasmania	6	Black	Westland	Westland Acc. Soc.
1898	Tasmania	7	Black	Wellington	Wellington Acc. Soc.
1898	Tasmania	9	Black	Buller River	Buller Acc. Soc.
1898	Tasmania	9	Black	Westland	Grey Acc. Soc.
1898	Tasmania	9	Black	Westland	Westland Acc. Soc.
1898	Tasmania	8	Black	Nile Valley	Buller Acc. Soc.
1898	Tasmania	10	Black	Lake Waikaremoana	?
1911	Australia	?	?	Poverty Bay	Murphy
1913*	Tasmania	2	Black	Wellington	H. Worsley
1915*	Tasmania	2	Black	Wellington	H. Campbell
1916*	Tasmania	1	Black	Riverlee, Taranaki	B. Rothe
1916*	Australia	1	?	Wellington	Wilson
1919*	?	1	?	Rai Falls, Marlborough	A. Prentice
1920*	Australia	1	?	Wellington	J.H. Davis
1924*	Australia	1	?	Wellington	J. Symonds

* Imported as pets

Administratively, by 1900 three government departments (Fig. 1.1) were involved in the management of introduced mammals on land where predominantly indigenous vegetation was present. The Colonial Secretary's Office (renamed the Department of Internal Affairs in 1907) was responsible for animal management generally, the State Forest Department was involved in management of mammals in areas where indigenous forest had been identified as potential production forests, and the Department of Tourists and Health Resorts was involved in animal management where tourism potential had been identified (for example game animals such as red deer) (McKinnon and Coughlan, 1963).

The Animals Protection and Game Act 1921-22 was the next piece of legislation to be passed controlling the management of wild animals, and was the controlling piece of legislation until the passing of the Wildlife Act 1953. Under the 1921-22 legislation possums were still protected, acclimatisation societies were still given considerable powers, and deer were classified as game. Newly introduced animals such as chamois and thar were also classified as game. Of interest, was the ability of the minister to designate specific areas as sanctuaries for both native and introduced fauna (McKinnon and Coughlan, 1963).

1.2.3 The emergence of pest status (1910-1960)

Early records of introduced mammal numbers (and goats in particular) are limited, although Thomson (1922) reports that their numbers were high in the Maitai valley, Nelson, in the 1840s and 1850s. Thomson, (1922) records B.C. Aston stating that the number of goats in the Ure (Isolated Hill, Southern Marlborough, field site of this study) were such that:

"the fusillades of stones showered down on us by the goats which we had disturbed were a source of ever present danger." Thomson, (1922, pg. 57)

In Central Otago feral goat numbers were conservatively estimated at 30 000 (Thomson, 1922) in 1916, and it was apparent that organised culling by runholders had been operating since before 1915. On several stations goats were culled because of competition with stock, on others they were encouraged because of their ability to eat out the 'native briar' (Thomson, 1922).

General animal control began between 1910 and 1920; although the acclimatisation societies had begun controlling deer as early as 1906 (New Zealand Forest Service, 1964) for trophy (ensuring that high quality heads were available for sport-shooters) rather than conservation reasons. In 1924 feral goats were culled on the slopes of Mt Taranaki (Parkes, 1996) by National Park staff, however, it was not until the formation of the Department of Internal Affairs Deer Destruction Unit in 1930 (Fig. 1.1) that widespread co-ordinated management of pests began.

The deer destruction campaign was a remedy to concerns in the 1920s that deer were damaging native vegetation in many places (McKelvey, 1995). It was intended that the deer destruction unit would only exist for a short time, but it became a New Zealand institution (Galbreath, 1993), and existed in some form or another until 1956 when the New Zealand Forest Service successfully annexed control of animal management on all forest lands. As part of its duties the Department of Internal Affairs Deer Destruction Unit controlled goats from 1931 onwards. This was primarily in the Marlborough region (McKinnon and Coughlan, 1961; McKelvey 1995) and was generally conducted during winter months (during the off-season from deer control). Widespread control of goats by government hunters did not begin until 1937 (Parkes, 1996). Between 1930 and March 1956 Internal Affairs hunters killed 654 457 animals classified as non-deer (this includes thar, chamois, and pigs) (McKinnon and Coughlan, 1961). More specific numbers for the period 1946-1957 are provided by Parkes (1996) who states that government hunters and regional bounty schemes accounted for 426 406 goats.

The 1950s were a period of considerable change in the management of introduced mammals in New Zealand. The passing of the Wildlife Act 1953 gave recognition to protected species (generally indigenous fauna), game species (redefined as birds only *e.g.* pheasant, quail), and other wildlife (Schedule IV) into which deer and other ungulates were classified. Inclusion in Schedule IV meant that an animal was to be controlled where it was present on crown land and acting in a deleterious manner. In section 11 of the Wildlife Act the somewhat ambiguous nature of goats was recognised - not only were they included in Schedule IV of the Act, but their special nature as agricultural animals was also recognised (McKinnon and Coughlan, 1963). The Noxious Animals Act 1956 was created to facilitate the transferral of wild animal control responsibility from the Department of Internal Affairs to the New Zealand

Forest Service. Some thought the new legislation had 'sinister' connotations for the sportsman (McKelvey, 1995) as mammalian herbivores were specifically reclassified as pests and not as game or wild animals.

The appointment of Thane Riney (a North American deer biologist) to the Wildlife Branch of Internal Affairs in the early 1950s substantially changed the approach to deer control in particular and the whole ungulate question in general (Galbreath, 1993). Riney (1958) attempted to redefine the context of animal control to one of animal management (in other words focusing on deer as a potential resource rather than only as a pest). He contended that we could approach wildlife problems in three simple ways:

1. we want a species increased in number;
2. we are happy with its current number and status;
3. we want its numbers decreased or reduced.

Riney contended that our situation in New Zealand was unique as we were dealing with mammals that were all introduced by humans. Hence, there was a feeling that in some way we were rectifying mistakes. Riney (1958) contended that we needed to consider management and research in terms of the land use of particular areas. Research needed to focus on both the land and the ability of the pest animals to respond to it (in other words their habitat selection and population dynamics). Riney suggested that funds needed to be directed at fundamental research into the animals so as to understand the interactions of animal and environment.

1.2.4 Conservation of indigenous values (1960-1999)

By the 1960s government policy had changed considerably; the Director of Forests A.L. Poole stated in 1964 that the aim of animal control was (Janson, 1994):

"to control [deer] at a level indicated as sufficiently low by the condition of the vegetation."

This marked a considerable change in the focus of wild animal control, away from semi-production values to ones that were explicitly about protection. However, Caughley and Sinclair (1994) contend that while there was a protection focus, the focus itself was primarily on prevention of accelerated erosion in watersheds, and only secondarily on protection of flora and fauna. Further, Caughley and Sinclair (1994) argue that programmes lacked clear measurable goals, a problem that was also typical of

feral goat operations throughout the same period (Parkes, 1990b). However, the criticism of lacking a protection focus is incorrect, for as early as 1923 concern was expressed on the impacts of deer, goats, and pigs in areas of indigenous forests by the Forest Service (McKinnon and Coughlan, 1960). This expression of concern led to the Departments of Agriculture, Tourists and Health Resorts, and the State Forest Service discussing with local acclimatisation societies how protection of deer in particular could be removed to allow control.

In the 1970s controversy again re-emerged over the policy approach to wild animal control. Clarification was sought via a Parliamentary Commission of Inquiry which sought to address the pest issues facing New Zealand at the time. Miers (1973) provided a distinction between game management and control. Management suggested a situation where objectives were seen to favour animal populations in some respect, whereas control suggested objectives that favoured the environment. Miers stated that in areas of concern control must outweigh management. However, he also recognised that recreational hunting should be encouraged, particularly in less critical areas. This was an important concession to the game management lobby, but was also an acceptance that recreational hunting could not control animal populations in many areas. Miers concluded by stating that "noxious animal control policies and practices should be seen to favour the environment as a whole, rather than promoting the harvesting of alien game mammals as the principal object of land use." The Wild Animal Control Act 1977 was formulated as an outcome of the Commission of Inquiry and a Government Caucus Committee report in 1974 which addressed matters relating to noxious animal control (Holloway, 1988). The act was aimed at controlling (managing impacts of) wild animals generally (eradicating where possible), and was also designed to regulate the activities of recreational and commercial hunting operations (Holloway, 1988). It was also important because it finally addressed the confusing legal status of goats (when and where goats were considered stock versus a feral animal), and clearly stipulated procedures that allowed the control of feral goats on and off crown land. Other Acts of this period that affect animal management include the Reserves Act 1977, and the National Parks Act 1980. Holloway (1988) reviewed a number of the statutes in terms of their application to the management of introduced mammalian herbivores in New Zealand. Holloway considered that Acts were either aimed at the management of individual introduced mammals (Wildlife Act 1953, Wild Animal Control Act 1977), or

were targeted at the management of tracts of land (Land Act 1948, Forests Act 1949, Reserves Act 1977, National Parks Act 1980). He suggested that this dichotomy had significant implications for how animal control was approached, and for how recreational hunters were viewed. The narrow focus on animal management required under the Reserves Act 1977 and the National Parks Act 1980 meant that eradication was the only option legally available (Holloway 1988, Parkes 1990b), which led to operational aims that were unsustainable in the long term and hence limited conservation gains. However, the Acts did at least focus attention upon the resources, as opposed to the mammals being controlled, a subtle difference that would not be implemented in practice for some years to come.

The 1980s were a period of change in the status of some introduced mammals and in the administrative structure of management of introduced mammals. In the early 1980s a sudden boom then bust international fibre market arose around goats (McKelvey, 1995). The market initially saw feral nanny goats fetching as much as $200 (M. Brennan *pers. comm.*), however, with the collapse of the market in the late 1980s the same animals were virtually worthless. One result of the entire boom and bust cycle was to increase the rate of re-infestation of feral goats from farms onto conservation lands (McKelvey, 1995).

In the early part of the decade moves were made to have all management of non-production lands, all conservation of indigenous flora and fauna, and all management of animals threatening indigenous flora and fauna placed in one central body (Galbreath, 1993). This led in 1987, to the formation of the Department of Conservation the national body that today manages conservation lands in New Zealand. To facilitate the creation of the Department the Conservation Act 1987 was passed; an Act which guided the management of natural resources in New Zealand, in which the emphasis is clearly placed in favour of indigenous flora and fauna (Holloway, 1988). However even at that late stage in the development of legislation dealing with management of natural resources, controversy emerged over the definition of the phrase "plants and animals of all kinds" (Holloway, 1988). The Act was definitely not intended to provide protection for introduced species, however in failing to include the term "indigenous" acrimony emerged. Holloway (1988) felt that this failure was indicative of the difficulty of forming legislation that effectively gave the Department the flexibility to manage the

range of situations present on conservation estate. This was rectified in the Conservation Law Reform Act 1990 in which Section 2 notes that nature conservation must have "special regard to indigenous flora and fauna, natural eco-systems, and landscape".

A change was also apparent in the philosophy of management. John Holloway (then Director of Land and Fauna, Department of Conservation) stated at a seminar discussing the future of the wild animals in New Zealand that the Department of Conservation's position on the management of introduced herbivores was:

"the impact of wild animals on conservation values varies in both degree and acceptability according to the intrinsic nature of the ecosystem, and the status accorded to it." (Holloway, 1988)

This marked an important change as it gave credence to the concept of focusing on the impact of pest herbivores rather than the pest species itself. Further, it accepted that not all lands administered by the Department of Conservation were of equal value, and that impacts by introduced herbivores were not equal.

Two further Acts have shaped Department of Conservation policy in the 1990s. The Resource Management Act 1991 provided a framework upon which planning for sustainable management of resources could be implemented. The concept of sustainable management of resources meant that the Department of Conservation had another statutory tool with which to implement control strategies for introduced mammals. The Biosecurity Act 1993 provided the statutory framework by which all pest organisms were to be managed in New Zealand. The Act does not replace the Wild Animal Control Act 1977 (under which the national pest control strategies have been prepared, see below), instead it provides an integrated approach to pest management, and in particular it aims to (Ministry of Agriculture and Fisheries, 1994):

- comply with international biosecurity and export requirements;
- maintain border controls and quarantine;
- maintain pest surveillance systems within New Zealand;
- develop and action national and regional pest management strategies.

Thus, where matters of national pest management concern occur on conservation land the Department of Conservation has a responsibility under the Biosecurity Act 1993.

In 1993 the Department of Conservation released the Thar Control Plan (Department of Conservation, 1993). This was the first of three published national pest control strategies (the other two are the National Possum Control Plan 1994, and the National Feral Goat Control Plan, 1998. All are published under the powers of Section 5, Wild Animal Control Act 1977. The focus was clearly upon prioritising areas:

"We have to decide what is tolerable, prioritise conservation values over the estate and set densities which do not unduly compromise these values, and organise the control and hunting agents to help protect these values." (Department of Conservation Thar Control Plan, 1993, pg. 1)

Despite these changes concern was still expressed over the way in which operational control programmes were enacted and monitored. Rogers (1995) argued that much animal control had failed because it was not sustained, or because operational goals had been vague and often unmeasurable. Rogers argued that performance monitoring was required; in other words focusing on the resource rather than the pest. However, by 1995, the Department of Conservation was well aware of such considerations. The work by Forest Research Institute scientists (McKelvey, 1995) in the 1980s (who later moved to Landcare Research Ltd. after the formation of the Crown Research Institutes) had clearly shown that performance monitoring in some form was required, and that it should concentrate on the resource rather than the pest *per se*.

The National Feral Goat Control Plan released in 1998 marked another change in policy outlook. It aimed to:

"maximise national conservation outcomes by setting policies and guidelines that maximise the efficiency, effectiveness, and sustainability of attempts to limit the effects of goats on conservation values.....raise public awareness for the need to ultimately reduce wild/feral goat numbers to very low goat densities in New Zealand as they are an economic and environmental pest." (Department of Conservation, 1998, pg. 2).

The plan recognised that pest issues go beyond conservation boundaries and that public involvement is critical in addressing pest management issues if the ultimate aim of controlling the pest is to be sustainable in the longer term.

Currently feral goats are present on approximately 500 discrete patches of conservation land; totalling approximately 20 000 km^2 (Parkes, 1996), and are managed on these lands by the Department of Conservation. Despite considerable change in the philosophy and management of introduced mammalian herbivores in New Zealand they remain a considerable problems in terms of impacts upon indigenous biodiversity

values. If it is considered that the three current national wild animal plans represent the forefront of conservation policy direction in New Zealand it is of concern that only one plan (the thar plan) makes any provision for or encouragement of either applied or basic research that may assist in ameliorating the impacts of the three pests on conservation land. As early as 1985 a government sponsored research committee reported on future research directions that were required for feral goats in particular; specific needs were identified in terms of seasonal diet and use of habitat (to assist in potential poisoning operations), movement subsequent to hunting, and overall distribution (Wildlife Research Liaison Group, 1985). The early 1990s have also been characterised by calls for better understanding of establishment and spread of introduced species (Townsend, 1991; O'Loughlin, 1993); research has been identified as the key contributor to this understanding.

1.3 The elements of the feral goat problem

Parkes (1991) states that pest management generically consists of three elements: the pest, a valued resource, and people who value the resource. On top of those elements the biology of the pest, the biology of the resource, management systems, and legislative statutes can be overlain. All interact in the implementation and delivery of a pest control programme, and are thus important in the management of pests.

While control strategies (management systems) for feral goats are well developed (Parkes, 1990a, 1990b, 1991, 1993; for a more general discussion, Bomford and O'Brien, 1995), the relationship between goats and the habitat they occupy (pest biology) is not well understood in the wild beyond the broad level of temperature and moisture acting as a limiting factor (Wodzicki 1950; Clark, 1974; Rudge and Campbell, 1977). Wodzicki (1950) noted that cool climate and high rainfall had restricted goats in provinces such as the West Coast and Taranaki, to local areas that were relatively dry. Clark (1974) in a population study of goats in the Taranaki region found that goats preferred warmer drier sites, especially in association with cover. Williamson (1975) provided a greater insight; in a study of feral goats at Tai Pari, French Pass, he noted that animals had high use areas that were typically dry, sunny, north-west and north-east facing, and afforded protection in the form of shrub cover and bluff systems. Rudge and Campbell (1977) in a study of feral goats on the Auckland Islands found that

streams and wet swamp areas limited the distribution of the goats. On farmland goats thrive in areas that are at least partially hill country, contain shrub cover, and sunny exposed outcrops (Yerex, 1986). However, little is known of the relative use of different vegetation communities by feral goats. This is of considerable concern as it is the impacts by feral goats on vegetation within communities that are generally quoted as justification for management of feral goat populations (Department of Conservation, 1998). Our direct measurement of impacts on vegetation through animal diet is better; six studies have analysed feral goat diet (Parkes, 1984; Mitchell *et al.*, 1987; Parkes, 1993; Cochrane, 1994; Chimera *et al.*, 1995; Stronge *et al.*, 1997) of which four have been on mainland New Zealand (this contrasts with two published diet studies for red deer, two for feral pigs, and 13 published or unpublished studies for possums (Cochrane, unpublished data)).

Previous studies of feral goats (Mitchell *et al.*, 1987; Cochrane, 1994) have suggested that the spatial heterogeneity of the areas that feral goats are present in is a key factor in determining the specific location and impacts of the animal. At a more general level Townsend (1991) states that an understanding of the reasons for successful establishment and the continued spread of invading species will improve the management decisions of the future. Hence our understanding of at least one element of the feral goat problem (spatial and temporal habitat selection) needs improvement if management of the pest is to likewise improve. Spatial and temporal habitat selection is critical in determining the impacts of introduced mammalian pests on indigenous flora and fauna, and is also critical for the functioning of effective wild animal control programmes.

It is hoped that this study will improve the understanding of feral goat habitat relationships within New Zealand, and will act as a catalyst to change the way in which management of pest species in general is enacted. This study has as its thesis that vegetation composition and structure directly affect feral goat habitat selection, and that feral goat habitat selection is altered by periodic intensive control campaigns.

1.4 Thesis overview

The thesis is arranged in five chapters (as outlined below).

Chapter 1: General introduction, elements of a pest problem, history of management of introduced herbivorous pests in New Zealand and legislative acts that influence pest control;

Chapter 2: The theoretical basis for habitat selection, habitat selection by members of the family Bovidae (in which goats are classified) in New Zealand, and overview of the study at Isolated Hill Scenic Reserve;

Chapter 3: Descriptions of the vegetation associations at Isolated Hill Scenic Reserve and Black Angel Creek;

Chapter 4: Habitat selection by feral goats at Isolated Hill Scenic Reserve and Black Angel Creek;

Chapter 5: Wild animal management by the Department of Conservation at Isolated Hill Scenic Reserve: does it match habitat selection by feral goats, the implications for conservation management of heterogeneous use of habitat, and general discussion and conclusion.

Chapter 2 - A literature review of theories of habitat selection and habitat selection by members of the family Bovidae in New Zealand

2.0 Chapter aim

This chapter aims to provide a review of the following areas:

- definitions of habitat, habitat selection and habitat suitability
- applications of habitat selection
- implications of optimal foraging theory for habitat selection
- habitat selection of ungulates at the landscape level
- habitat selection of the family Bovidae (thar, chamois, sheep, cattle, goats) in New Zealand

The chapter concludes by providing specific details of the experimental aims and structure of the thesis.

2.1 Definitions

Caughley and Sinclair (1994) defined habitat as "the suite of resources (food, shelter) and environmental conditions (abiotic variables such as temperature and biotic variables such as competitors and predators) that determine the presence, survival, and reproduction of a population." The definition implies a spatial and temporal component. The definition of habitat for this study is modified from that of Hall *et al.*, (1997). The definition used here is:

Habitat: the assemblage of resources and conditions present in an area that determines spatial use, and temporal survival, of an animal.

Hall *et al.*, (1997) included the term occupancy in their definition. Jorgensen (1997) pointed to the term occupancy producing potential triviality in definition of habitat. Jorgensen presented the example of a deer swimming across a lake. This satisfies the requirement of the Hall *et al.*, definition, but clearly was not the intent of the definition.

Whilst Hall *et al.,* further defined habitat as an area that supports at least some of the needs of the organism, Jorgensen stated that a literal interpretation of this produced a potentially misleading definition. Hence, in this study, repeated spatial and temporal use of areas within the environment must occur, before those areas are considered habitat. This addresses the concern expressed by Jorgensen (1997). Habitat in this study consists primarily of a variety of different vegetation communities. Vegetation communities are defined in Chapter three. Other terms that will be used in this study are:

Habitat selection: the manner in which an animal chooses and uses specific habitat components on a number of nested spatial scales.

Habitat suitability: the ability of a habitat to provide for the needs of a particular animal at a particular time.

2.1.1 Applications of habitat selection

The development of Habitat Suitability Index Models (HSI) and Habitat Evaluation Procedures (HEP) in the United States has led to improved management of a wide range of animal species (Pearsall *et al.*, 1986). The philosophy of HSI model development and management of valued species differs markedly from the philosophy of management of introduced pests, however, there is potential for pest management to be improved by adopting at least some of the elements of the HSI processes.

In the United States prior to 1969, management tended to emphasize game species and wildfowl values (Pearsall *et al.*, 1986). In 1969, the National Environmental Policy Act changed that focus to one of conservation of flora and fauna. As a direct result of this government agencies have developed various habitat evaluation models in an attempt to measure impacts of management. Seven trends have dominated the shift from managing game to understanding how management practices impact upon habitat and animals (Pearsall *et al.*, 1986).

1. Habitat is treated as being synonymous with environment.
2. Habitat quality for an animal species is equated with the carrying capacity of its environment.

3. Species – habitat models have been produced with *a priori* judgements supplemented by empirical data.
4. Modelling of species-habitat relationships has evolved through four stages; conceptual, diagrammatic, symbolic, and computer based.
5. There is a tendency to establish rigid forms and exact procedures for evaluating habitat.
6. The subject area is well integrated, with new approaches based upon previous endeavours.
7. There is interest in establishing a single standard approach to habitat evaluation based upon:
    a) information on animal diversity and distribution;
    b) habitat definition and life history requirements;
    c) species-habitat models;
    d) habitat availability and quality;
    e) habitat responses to management practices.

Habitat suitability models assume that wildlife populations and their selection of habitat are a function of the spatially and temporally available components of an environment (Patton, 1992) (Table 2.1 reviews the general steps involved in developing an HSI model). Patton (1992) stated that the most often used elements are food, cover, water, and space, and that they can be related conceptually using the following equation:

$$HQ = f(Fo + Co + Wa + Sp) \qquad \text{Eq. 2.1}$$

Where:
HQ = habitat quality
Fo = food
Co = cover
Wa = water
Sp = space

The HSI models use a more general form of equation (in which *V* represents habitat factors) (Patton, 1992):

$$HSI = (V_1 + V_2 + V_3 \ldots V_n)/n \qquad \text{Compensatory model} \qquad \text{Eq. 2.2}$$

or

$$HSI = (2V_1 + V_2 + V_3 \ldots V_n)/n \qquad \text{Weighted mean} \qquad \text{Eq. 2.3}$$

or

$$HSI = (V_1 \times V_2 \times V_3 .... \times V_n)^{\frac{1}{n}}$$ Geometric mean Eq. 2.4

Models are able to take the form of additive relationships (as shown in equation 2.1 and 2.2), limiting factor relationships (in which the variable with the lowest suitability overrides other variables), and compensatory relationships (in which variables with low suitability can be offset by variables of high suitability) (United States Fish and Wildlife Service, 1981). HSI models produce habitat indices with a value of between 0 and 1 (as all variables have a value between 0 and 1), which can be directly compared to rank habitat in terms of its suitability for a particular animal species.

Table 2.1 The general stages in developing the Habitat Suitability Index (HSI) score for a specific vegetation community (after Pearsall *et al.*, 1986).

Stage	Description
1	*Key habitat components*: key habitat components are determined for the stand type and the species in question.
2	*Key habitat variables*: key habitat variables are selected which will assess the relative habitat value of the components in the stand for the species.
3	*Key variable weights*: key variable weights are assigned to distribute importance among the key habitat variables.
4	*Field methods*: key habitat variables are measured in the field yielding certain values.
5	*Transformation curves*: these values are plotted on transformation curves which then yield suitability indices for the key habitat variables.
6	*Mathematical relationships*: the suitability indices and their appropriate weights are then related mathematically to yield a final HSI score.

When available habitat for a selected species in the evaluation area includes more than one cover type (Pearsall *et al.*, 1986), *i.e.* more than one vegetation type, the final HSI for the evaluation area is calculated as an average weighted by area:

$$HSI = \{\sum (HSI_i \times a_i)\} / A$$ Eq. 2.5

Where:
HSI_i = the index for the ith stand
a_i = the area of stand i
A = the total area of all stands

Another approach is pattern recognition modelling (Pearsall *et al.*, 1986). Such models plot the density of animals in habitats against a large array of habitat variables and then identify patterns of coincidence. Van Horne (1983) cautioned that biologists seldom question the assumption that the density of a species in a habitat is a direct measure of the quality of the habitat. Van Horne also cautioned that management based strictly on abundance and level 2 and 3 descriptions (Fig. 2.1) could be misleading. Van Horne (1983) stated that our knowledge of species requirements is poor, and synergistic effects

between resources are often ignored. Seasonal effects potentially drive survival within a particular habitat. Van Horne (1983) gave the example of northern deer where the availability of winter range contributes disproportionately to carrying capacity. Hence, estimations of habitat quality based upon summer densities are misleading, as summer habitat may not contribute to population survival through winter. Further, there can also be among-year variability in local population densities due to small-scale differences in food, or in abiotic environmental factors. Hence densities may reflect resource levels that have been recently consumed or experienced rather than current habitat quality *per se*. Van Horne noted that other factors such as behavioural interactions (for example the role of sub-dominants in the utilisation of sub-optimal habitat) also needed to be considered. Thus, high density alone cannot be used to infer habitat quality. Instead habitat quality should incorporate measures of density, survival probability, and mean expectation of future offspring for residents in one area compared to another (Van Horne, 1983).

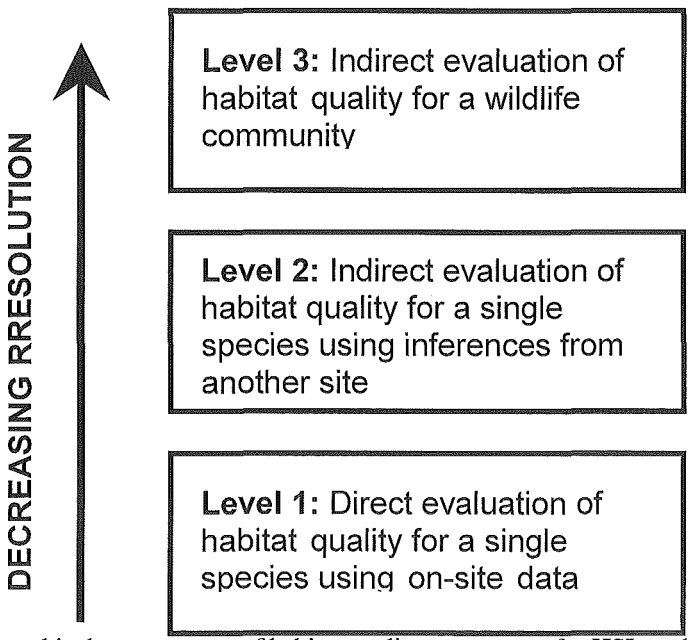


Figure 2.1 Hierarchical arrangement of habitat quality assessment for HSI modelling (after Van Horne, 1983).

Management of ungulate species in Southern Africa also provides a source of wildlife-habitat relationship models. Novellie and Winkler (1993) calculated HSI values for habitat prior to the reintroduction of Cape Mountain Zebras (an HSI was also required to allow monitoring of habitat so as to prevent degradation and change). The HSI was

derived from percentage aerial cover of different grass species in the habitat and an index of acceptability of each grass species to zebras. Only grass species were considered as it was found that other species made up only a negligible amount of the zebra diet. A year round acceptability index was calculated rather than a seasonal one. The HSI was calculated as follows:

$$HSI = \sum a_i c_i \qquad \text{Eq. 2.6}$$

Where:
a_i = acceptability index of species i
c_i = the percentage aerial cover of species i

Whilst HSI models have been aimed at assessing habitat suitability for vertebrates that are of either economic or conservation value, applying habitat suitability models to conservation pest species has considerable merit. The model approach forces scientists and managers to think of an organism in terms of its basic biology, directing and focusing research and management towards identifying habitats which can then be used in the implementation of effective control programmes. Uncertainty over location of pest species at particular times of the year could be reduced. This would have the benefit of reducing hunter search time. Further, habitat models have the added advantage of identifying potential habitats in areas where pests are not present. Such knowledge could be used to prevent range expansion of pest species through surveillance of "likely" habitats.

2.1.2 Optimal foraging theory: a framework for habitat selection

Optimal foraging theory considers the foraging patterns of animals in terms of maximisation of net energy gain per unit of time (Schoener, 1987). Optimal foraging theory evolved as a means of exploring and testing hypotheses about the relationship between predators and prey. The theory of optimal foraging, in particular the sub-theory of optimal patch selection is a useful framework in which to consider habitat selection.

McArthur and Pianka (1966) published a seminal paper that initiated the interest in the area of optimal foraging. Their thesis was that two aspects of dietary items were important:

1) their dietary contribution in terms of taste and nutritive quality;
2) the search time to locate them within the environment.

McArthur and Pianka stated that the activity of searching for an item should be enlarged as long as the resulting gain in energy exceeded the loss (search-time spent per unit of food). McArthur and Pianka stated that each food item (and in an expansion to their theory, habitat patch) could be divided into time per item to search, and time per item to catch or utilise. If items (or patches) could be ranked from most profitable to least profitable then optimal diet (and habitat selection), could be calculated by proceeding through the list until the energy gain per unit of search time became negative (McArthur and Pianka, 1966). Schoener (1987) stated that a concern of the expansion from diet to habitat patch selection is that an assumption was made that patches could be treated in an analogous manner to prey so far as encounter and value were concerned. Schoener noted that foragers tend to deplete patches rather than just consuming them (as in the situation of a predator/prey relationship).

A sub-theory of optimal foraging, the ideal free distribution (and the despotic distribution) developed by Fretwell and Lucas (Fretwell and Lucas, 1970, in Harper, 1982) considers the situation where competition may reduce the attractiveness of a patch of high prey density. The theory assumes that competitors utilise prey patches in a manner such that each individual receives the same amount of resource (Harper, 1982). Thus, competitors distribute themselves in terms of the ratio of reward encountered in different patches at different levels of competition. There are four key assumptions within this model (Milinski, 1987):

a) each individual is free to move to where its chance of reward is greatest;
b) habitat suitability decreases with increasing competitor density;
c) habitats are homogeneous in terms of survival factors;
d) all individuals are equal in terms of competitive ability and resource needs.

Empirically the model can be thought of as (Gray, 1994):

$$\frac{N_1}{N_2} = \frac{R_1}{R_2} \qquad \text{Eq. 2.7}$$

Where:

N_1 = the number of animals at site 1
N_2 = the number of animals at site 2
R_1 = the reward level at site 1
R_2 = the reward level at site 2

The despotic distribution model accounts for competitors that are able to dominate or monopolise resources through some form of behaviour (Harper, 1982). Harper (1982) reported a test of the ideal free model using mallards that were given a choice of patch quality and allowed to distribute themselves. Despite violating the assumption of equal competitive ability (dominant mallards monopolised the food resource) the overall distribution of mallards was similar to the *a priori* predictions of the ideal free model (Harper, 1982). Gray (1994) considered synthesizing biological and psychological approaches through psychological matching laws and the ideal free distribution. The matching law uses the form $B_1/B_2 = c(R_1/R_2)^a$, where c is a measure of bias and a is a parameter that describes the animal's sensitivity to reinforcement. Gray suggested that the inclusion of a perceptual threshold, below which animals are not able to perceive differences in patch quality, could improve predictions made with the ideal free distribution. Gray (1994) stated that future models needed to explore the consequences of individual behaviour in terms of perceptual ability, and ask whether particular cohorts of a population (for example dominant animals) fit the ideal free distribution.

The development by Charnov (1976) of the marginal value theorem addressed the assumption that patches were depleted and not consumed. The marginal value theorem assumes that the consumer depresses the availability of food to itself, hence in any given patch availability drops. The theory predicts that a consumer would leave the patch when the marginal capture rate for the patch drops below the average capture rate for the surrounding patches. Sih (1980) suggested a modification to reduce the focus on maximisation of net energy intake. Sih (1980) stated that other factors could also be important, in particular the risk of predation. Foragers therefore must choose a strategy that balances the risk of predation with net energy intake. The move away from diet as the dominant determining factor had been addressed earlier by Wecker (1964) in a study that found that organisms tended to be restricted in distribution by behavioural and physiological responses to the environment. Wecker suggested a potential psychological factor in habitat selection in that a deficiency in certain cues could lead to an organism not using an otherwise suitable patch of habitat. Wecker (1964) found that

prior experience was not a prerequisite of habitat selection, hence, an innate component was involved in selection of habitat. Schoener (1987) noted other deviations from the pure optimal foraging theory. For example, partial preferences could exist, or nutrient constraints could be included in models (as optimal energy intake is not necessarily related to optimal nutritional requirements). Further, Schoener noted that plant secondary compounds could necessitate a wider range of diet than optimal foraging theory would predict. A diversification of diet was needed to ameliorate the damaging effects of particular plant toxins either through reducing concentration, or through aiding in detoxification (Schoener, 1987). Schoener also recognised that rate of digestion (gut passage time) could cause deviation from optimal foraging and patch selection, if the time for a food item to pass through the digestive system became a limiting factor rather than search time per food item.

Rosenzweig (1981) considered the application of foraging models to habitat selection and was critical of the way in which many models did not consider that habitat selection contained costs. For example, many models did not incorporate the time and energy required to search for preferred habitats. Rosenzweig (1981) also defined a series of terms that described how animals utilised habitat. These terms (such as generalist, specialist, opportunist) referred to the behaviour of a phenotype of the species in question. A generalist was defined as one whose fitness in one patch precisely equals its fitness in the other. A specialist was defined as an organism that has unequal fitness in different habitats. Opportunistic or fine-grained means an organism that accepts resources in the proportions in which they exist. Coarse-grained behaviour means an organism selects resources in proportions different from those in the environment. Rosenzweig (1985) was equally concerned for the manner in which the terms specialist and generalist were used. The terms were used to describe both behaviour and foraging abilities. Rosenzweig (1985) defined a generalist as "an individual able to use all habitats equally well" and, specialists as "more adept at using some subset of habitats". A selector was defined as an individual that uses habitat independent of its availability, an opportunist as an individual that uses habitat in proportion to its availability (Rosenzweig, 1985).

Tests of optimal foraging theory have shown that widely varying taxa do exhibit optimality in some part of their suite of behaviours. Diamond (1984) reviewed an experiment of humming bird feeding and territory size that investigated whether

humming birds optimized territory size to ensure maximal return of nectar. The study revealed that humming birds used a process of trial and error (learning) until they had optimally maximised territory size and hence the rate of weight gain. Dunbar *et al.*, (1990) applied optimal foraging theory to the situation of mating strategies for feral goats. Feral goats exhibit a polygynous mating system in which dominant males determine access to females. Females live in small, relatively stable groups each occupying its own home range with limited overlap with other female groups. To reduce costs associated with rutting, male goats may choose to join groups with fewer males, or they may indulge in the behaviour of kleptogamy (a behaviour in which sub-dominant males mate with females while the dominant male is elsewhere) (Dunbar *et al.*, 1990). Dunbar *et al.*, (1990) found optimal foraging did not necessarily describe the behaviour of male goats, in particular young males. Dunbar *et al.*, found that young males were often attracted to large groups of females, despite the presence of dominant males. Young males were recorded partaking in alternative strategies (for example kleptogamy) suggesting that an element of learning was involved in the process of mating (Dunbar *et al.*, 1990).

Opponents to optimal foraging have emerged as the theory has established itself. Ollason (1987) asserts that "it is pointless" to try to differentiate between learning models and optimal foraging models in the context of animals in regenerating heterogeneous environments. Ollason states that animal learning and not set stimuli allow animals to forage effectively within environments. Hence, animals have evolved the ability to respond to changing environments, rather than evolving a set of behaviours that respond unchangingly to specific stimuli within the environment (Ollason, 1987). Potentially the juvenile male goats studied by Dunbar *et al.*, (1990) exhibit such ability. Schoener (1987) is critical of many of the opponents of optimal foraging models, stating that in many cases opponents over-interpret the findings of optimal foraging research. Schoener classifies criticism into three broad categories:

a) anti-adaptionist criticism (which claims that optimal foraging makes *a posteriori* rather than *a priori* arguments);

b) non-evolutionary mechanistic argument (proponents argue that optimal foraging theory is unnecessary and tends towards circularity);

c) plant toxin avoidance criticism (plant secondary compounds deter or prevent herbivory).

Schoener (1987) considers the criticisms of the anti-adaptionists to be generally misinformed, the criticisms of the non-evolutionary mechanists to be potentially enriching, and the arguments of the plant toxin proponents to be at best a special case and more importantly a potential constraint that could be introduced into optimal foraging models. Schoener (1987) makes a cautionary note that optimal foraging models are just that, models that help us to interpret patterns of foraging animals. Bell (1991) agrees with this noting that optimal foraging theory is a valuable tool for stimulating and interpreting studies of animal foraging patterns. Ward (1993) notes that even if an animal consistently maximises its net rate of energy intake by preferentially foraging at the more concentrated food sources this is not evidence that they are optimising, merely that the data is congruent with the predictions of an optimal foraging model. Bell (1991) notes two further areas of concern in optimal foraging; the assumption of absolute knowledge, and the utilisation of average behaviour or response. The assumption of total knowledge of an environment returns to the concern of Ollason (1987) about the role of learning in foraging behaviour. Logically, it appears unreasonable to assume absolute knowledge of an environment for a forager, although Schoener (1987) notes that learning through the process of sampling can be incorporated into optimal foraging models as a form of constraint. Bell (1991) notes that it would be interesting to investigate the level of knowledge in animal populations, and at what cost that learning occurs. The second area, the use of average behaviour or response, is potentially of greater concern (Ward, 1993), especially if optimal foraging is to be used as a framework for characterizing the foraging behaviour of a conservation pest such as feral goats. The interpretation becomes a question of scale (see section 2.1.3) in that if inferences are to be made about a population as a whole acceptance of the average (and realisation that individuals will deviate from this average to a degree) appears reasonable, whereas if the interest is at the sub-population level then individual behaviour is a more appropriate scale to investigate at. From a conservation perspective control for an average response may lead to the selection of a sub-set of the population that exhibits an atypical response.

Notwithstanding the criticisms of optimal foraging theory, the underlying reasoning of deriving maximum energy intake per unit of time is a useful framework for investigating the habitat selection behaviour of feral goats. Whilst diet is not necessarily indicative of energy intake for herbivores (as dietary items may be included for purposes other than maximal energy intake), a model based on the principles of the

optimal foraging theory will allow deviance from an optimal model to be calculated. This is of particular importance for investigating the existence and influence of factors other than diet in determining feral goat habitat selection. Ward (1993) stated that often several models might explain empirical observations equally well.

2.1.3 Habitat selection at the landscape level

Having defined habitat selection as *the process by which an animal chooses which habitat components to use* and also having introduced the concept of a multi-scalar process it is necessary now to define the scale at which this thesis intends to investigate feral goat habitat selection.

What does scale refer to? Schneider (1994) defines scale as "denotes the resolution within the range of a measured quantity". Hence scale can be equally applied spatially as well as temporally. Schneider (1994) gives an example of studying leaf litter fall for a single tree in a 100 ha study area for a temporal period of two years. Scale is an important concept in the study of habitat selection, as it is necessary to understand whether an animal is being studied as an individual, as a small group of related individuals, or as a population. Similarly a temporal scale is necessary; is the population being studied for a day, a season, or a decade?

This study focuses on habitat selection at the scale of a feral goat population. In a study of birds Wiens (1985) reported that at the most general, biogeographic scale, clear and strong associations between bird populations and habitat elements were recorded. This was expected, as at that scale a broad range of quite different habitat types was included (Wiens, 1985). As the scale was reduced some patterns disappeared and others emerged, but associations weakened. Dunning *et al.*, (1992) stated that investigations of processes that affected populations needed to be done at a scale relevant to both the organism and the process under study. Dunning *et al.*, (1992) noted the landscape scale was frequently used and that this could be defined for animals as a scale operating between an organism's home range and its regional distribution. For feral goats at Isolated Hill Scenic Reserve this means a scale that operates at the level of the whole reserve.

Landscape ecology focuses on the spatial patterns of landscape mosaics and interactions among their elements (Wiens, 1992), and hence offers a particularly useful framework within which to characterise habitat selection. In a review of 99 published studies in *Landscape Ecology*, Wiens (1992) found the spatial scale of studies ranged from a few hectares to the scale of many square kilometres, and concluded that landscape ecology was focused on broad-scale features of land use.

Pickett and Cadenasso (1995) noted that throughout most of the history of ecology, scale has been assumed to be homogeneous for the sake of simplicity. Landscape ecology however assumes the exact opposite, embracing spatial and temporal heterogeneity. Landscape ecology can be used in abstraction to describe spatial and temporal heterogeneity at a variety of different scales (Pickett and Cadenasso 1995). The term used in landscape ecology to define scale is grain size (Norton and Lord, 1990). Forman (1995) defines grain size as the average diameter or area of all units present within a landscape mosaic. This contrasts with the use of the word grain encountered in section 2.1.2. Rosenzweig (1981) used the term grain to define how an animal utilised resources. A fine-grained animal was one that accepted resources in the proportions at which they were presented, whereas, a coarse-grained animal selects resources in proportions different to that encountered in the environment (Rosenzweig 1981). Norton and Lord (1990) commented on the multiple use of the word grain in ecology, noting that at least three different uses could be found, although all were interrelated. Wiens (1990) agreed with Norton and Lord (1990) that the use of the word grain in ecology was confusing, noting however that all three uses of the word were in some respect dependent upon the scale of observation. Wiens (1990) advocated using grain to refer to the finest scale of resolution of pattern possible within a given set of observations.

Mysterud and Ims (1998) stated that in the case of coarse-grained animals preferential habitat use could be inferred through the disproportionate usage of available habitat units. A suitable area would contain a mixture of habitats that provided opportunities for all essential activities required for successful reproduction. Most mammals, especially females adjust their home range size to resource levels, hence, when food is a limiting factor home range size will be adjusted to include a certain minimum amount of food (Mysterud and Ims, 1998). Hence, spatial scale is particularly important when habitat mosaics are involved. The concept of home range adjustment is further

supported by Tufto *et al.*, (1996) who hypothesised that individual animals utilise the minimum area that can meet their energy demands. Further, Tufto *et al.*, (1996) noted that heterogeneous landscapes may have the added benefit of complementary consumption of required resources (where an animal seeks different resources within an environment), for example nutrition and cover (thermal regulation or predation) requirements may be available within a single patch. Tufto *et al.*, (1996) hypothesised that edges between patches may be more important in that they provide access to a greater diversity of resource in a shorter temporal period or spatial area. Bowyer *et al.*, (1998) further developed the theme of satisfying multiple resource needs within a landscape, by stating that habitat selection is a function of required resources and predation avoidance. Thus, selection of habitat may be on the basis of minimising the ratio of predation risk to available forage. If intraspecific competition is also considered, the ensuing system can be thought of as one where dominant individuals occupy the best sites, and sub-dominant animals arrange themselves in other sites until either the risk of predation is too high or forage quality is too low.

In an investigation of gazelle foraging at different spatial scales Ward and Saltz (1994) found changes in seasonal foraging patterns. Ward and Saltz (1994) compared the observed foraging to that predicted by optimal foraging theory. They considered that the gazelles were optimising, but the optimisation was for a suite of reasons rather than nutritive reward alone. Gazelles turned right and left whilst foraging. In areas of high lily density they move a shorter distance between turns. Gazelles were observed to repeatedly sample within foraging areas before moving to other foraging areas. This reflected a lack of spatial and temporal memory, responses by grazed plants (for example the production of new leaves), and behavioural responses to other herbivores.

Senft *et al.,* (1987) explored the interaction between optimal foraging and landscape ecology. The application of optimal foraging theory to large herbivores has been problematic, as optimal foraging is primarily a theory developed from nectar feeders and predators. Herbivores tend to confront an apparent food surplus, which is generally of low and highly variable nutritive quality (Senft *et al.,* 1987). Often, food is widely scattered across a landscape rather than concentrated in discrete patches, hence large herbivores interact with resources at a variety of temporal and spatial scales. Thus ecologists have tended to concentrate on behavioural rather than evolutionary outcomes. Senft *et al.*, (1987) developed a conceptual framework that could span levels of

ecological resolution from plant community to region. They noted that it was appropriate to define the scale of resource selection by animal perception and foraging responses. Senft *et al.,* (1987) noted that herbivores perceive relatively consistent vegetation communities that are clustered in conjunction with soils or patterns of disturbance. In turn communities cluster in conjunction with geomorphic features to form landscape patterns. Regional systems are large-scale assemblages of landscapes (Senft *et al.*, 1987).

Importantly Senft *et al.*, (1987) elucidated a model of herbivore foraging at the landscape level. The model (which considered foraging behaviour) had the following characters:

1) foraging behaviour is at the level of feeding area selection rather than diet selection;
2) the aggregate behavioural response of the herbivores will be one of matching;
3) the hypothetical foraging goals are aimed at optimising foraging efficiency;
4) the interactive factors are forage biomass and nutritive quality.

Senft *et al.*, (1987) defined matching as herbivores adjusting their foraging behaviour to changing dietary rewards. They postulated that an animals' relative preference for plant communities (the ratio of the proportion of total feeding time in a community relative to the proportion of area occupied by the plant community in home range area) is generally a linear function of the relative abundance and/or nutritive quality of the preferred plants in the communities (Senft *et al.*, 1987). Hence, plant communities that contain a greater biomass of preferred species will be selected more often and utilised more by herbivores than those communities that have lesser amounts of preferred plant species. As evidence of this at a landscape scale, Senft *et al.*, noted that animals will stay longer in plant communities that have higher densities of preferred foods, or, alternatively will spend less time in communities that do not have high densities of preferred foods.

2.2 Habitat selection by the family Bovidae in New Zealand

New Zealand has five extant feral or wild species from the Bovidae (King, 1990). They are cattle (*Bos taurus*), sheep (*Ovis aries*), feral goats (*Capra hircus*), thar (*Hemitragus jemlahicus*), and chamois (*Rupicapra rupicapra*). Of the species present in New Zealand, four belong to the sub-family Caprinae (sheep, feral goats, thar and chamois).

Cattle belong to a separate sub-family, Bovinae (King, 1990). Two other members of the Bovidae family, the gnu (*Connochaetes gnou*) and the bharal sheep (*Pseudois nayaur*), introduced in 1870 and 1909 respectively, did not establish. Until recently habitat selection by members of this family has been poorly understood.

2.2.1 Habitat selection by feral cattle and sheep in New Zealand.

Feral cattle are present in relatively localised areas on mainland New Zealand (Taylor, 1990), and tend to utilise densely vegetated areas that provide substantial cover. Taylor (1990) notes that this is an artefact of hunting rather than an indicator of habitat preferences *per se*. Where feral cattle were present in the Clarence River Reserve (located inland from Kaikoura, approximately 50 km south of Isolated Hill Scenic Reserve) utilised habitat was typically densely covered in introduced rose-hip (*Rosa rubiginosa*) (M. Morrisey, pers. comm.). During winter months (when much of the inland Kaikoura region experiences snow-fall) feral cattle were found in areas of dense shrub cover (M. Brennan, pers. comm.). Feral cattle were also recorded utilising valley floors, terraces and wide ridge tops (Taylor, 1990).

Feral sheep habitat relationships are better known in New Zealand partially due to the concentration of feral herds in New Zealand (of 39 recognised feral sheep populations in the world, New Zealand has 11 (Rudge, 1983)). Parsons (1980) reported feral sheep utilising indigenous forest areas and open tussock and grass faces of the Woodstock area in Canterbury. Sheep were generally observed on hillsides with a north, north-east or east aspect. Bush-fringed clearings were recorded as common feeding grounds, although some animals were observed at distances of up to 500 m from significant cover. Evidence was found of sheep browsing on *Coprosma* leaves and fruit, and on *Nothofagus* seedlings (Parsons, 1980).

In a study of a protected feral sheep herd on Pitt Island (near the Chatham Islands, east of New Zealand), Rudge (1983) noted that preferred areas were sheltered, while tall grassland and shrubland areas were avoided. Analysis of rumens from sheep (Table 2.2) revealed that browse from shrubs, dicotyledonous herbs and ferns contributed only a minor proportion of the total diet (Rudge, 1983).

Table 2.2 General diet of Pitt Island feral sheep from 23 animals autopsied in 1980 (Rudge, 1983).

Food type	Mean % Volume
Grasses	95.39
Dicotyledonous herbs	1.50
Dicotyledonous shrubs	2.64
Ferns	0.46

Orwin and Whittaker (1984) recorded habitat selection by feral sheep on Arapawa Island in the Marlborough Sounds. Sheep were recorded using steep (circa 25°) slopes with outcropping bluffs. Preferred areas had soils that were fast draining (foot rot was recorded as absent from the feral sheep flock). Preferred feeding habitat was shrub/grassland and grassland communities. Sheep were regularly using nearby forest stands for shelter, shade, and as a source of browse (Orwin and Whittaker, 1984). Ballance (1985) investigated the population characteristics of feral sheep on Campbell Island (New Zealand, Subantarctic). Ballance noted high sheep density on unstable slips on which introduced grasses were growing. *Dracophyllum* shrubland was used as cover during inclement weather; more exposed sites, such as cliffs were only used during summer months.

2.2.2 Habitat selection by chamois and thar in New Zealand.

Thar (*Hemitragus jemlahicus*) and chamois (*Rupicapra rupicapra*) were introduced into New Zealand for sporting reasons in 1904 and 1907 respectively (Thomson, 1922). Both species have established and dispersed throughout the Southern Alps of the South Island, although chamois have dispersed considerably further than thar (Forsyth, 1997).

Christie (1963) recorded seasonal habitat selection by chamois in the Cupola Basin, Southern Nelson. Temporal variation in habitat selection was not great, although during winter chamois were observed on exposed ridges where snow was unable to accumulate, and on ridges close to beech forest. During periods of heavy rain or snow-fall chamois were recorded to enter scrub and forest areas (Christie, 1964), and feeding activity was less (Christie, 1967). In summer chamois regularly sought shade or permanent sections of snow, reflecting perhaps their thicker coat and their derivation from an alpine situation in Europe (Christie, 1967). Chamois were diurnal with maximum feeding activity during early morning and late evening (Christie, 1963). Chamois densities were highest in areas of well-drained slopes in which the dominant vegetation was *Poa colensoi*. Rock outcrops and areas of beech forest and scrub were also present suggesting that chamois preferred areas that had contiguous cover. No preference was shown for aspect by chamois, although red deer in the same basin

showed a consistent preference for northerly aspect sites (Christie, 1963). Densities of 0.02 – 0.03 chamois per hectare were recorded (Christie, 1963). Clarke and Henderson (1981) in a study of a naturally regulated population of chamois in Basin Creek, Avoca River region, noted distinct behavioural differences between sexes in how habitat was utilised. Males were more transitory whereas females generally remained within the area during the period of the study (1973 – 1978). Clarke and Henderson (1981) suggested that a dynamic equilibrium relationship between chamois population numbers and the vegetation resource had been reached, and that vegetation availability during winter months limited the population. Clarke and Henderson (1981) estimated a population density at approximately one chamois per 25 ha (0.04 animals per hectare). Clarke and Henderson (1984) investigated habitat utilisation and home range of female chamois. They found that home ranges matched the physiography of the area (predominantly narrow slopes). Key activity areas were defined for eight individuals and ranged in size from 0.8 to 4.5 ha. Activity centres were associated with preferred feeding sites (herbfields, grasslands, and shrubland areas). Internal home range use was particularly heterogeneous, which may reflect the extreme patchiness of vegetation in Basin Creek. Summer and winter range utilisation was markedly different; in winter animals favoured steep rocky areas and upper forest areas, whereas in summer the entire home range was utilised (Clarke and Henderson, 1984). Clarke (1986) in a study of movement and habitat use of chamois in the Avoca River region noted that feeding activity accounted for 50 - 80% of total habitat use, and resting activity 19%. Chamois mainly used grassland (this was the predominant vegetation of the area); mean annual use was 35.3% for alpine bluff grassland, and 27.8% for alpine grassland (Clarke, 1986). Use of the alpine grasslands peaked in late summer, and declined in winter as snow covered the area, while in winter there was a corresponding increase in the use of snow-free bluffs. Montane grasslands were moderately used (annual use 12.8%), less so where sheep were grazing. Shrubland was used as a source of food and shelter throughout the year (12.3%). High alpine barrens and screes were also moderately used (13.8% combined), Clarke (1986) noted that use peaked in winter. Fell-field use was limited (6.1%), and forest use was low (2.2%). Aspect use was mainly northerly during winter and southerly during summer (Clarke, 1986).

Parkes and Thomson (1995) investigated diet overlap in thar, chamois and possums occurring in sub-alpine and alpine areas of the Southern Alps. They found that chamois consumed more woody plants and herbs than thar or possums (Table 2.3). Parkes and

Thomson (1995) also noted that chamois diet was variable; chamois analysed from west of the main divide ate significantly more woody plants and less grass than chamois analysed from east of the main divide.

Table 2.3 Comparative food types in the diet of sympatric thar, chamois and possums in a subalpine-alpine environment (Parkes and Thomson, 1995) (sample sizes were thar, n=134; chamois, n=33; possums, n=40). Diet was analysed from rumen and stomach samples.

Food type	Mean % for thar	Mean % for chamois	Mean % for possums	Significance
Grasses	55.7	17.0	1.4	0.001
Woody plants	26.6	54.3	48.2	0.001
Herbaceous plants	16.3	28.4	44.5	0.001

Forsyth (1997) investigated whether sympatric chamois and thar behaviourally affected one another in terms of habitat selection in the Southern Alps. Habitat selection was recorded for both chamois and thar (Tables 2.4a and 2.4b) in the Carney's Creek area, Canterbury from 1993 – 1996.

Table 2.4a Seasonal use of habitat by chamois in the Southern Alps of New Zealand (Forsyth, 1997).

Habitat type	Spring	Summer	Autumn	Winter
Grassland	preferred	preferred	preferred	covered in winter
Grass bluff	avoided	avoided	preferred	preferred
Rock bluff	preferred	avoided	avoided	preferred
Scree	slightly preferred	avoided	avoided	avoided
Shrubland	preferred	preferred	preferred	highly preferred
Snow	avoided	avoided	avoided	avoided

Table 2.4b Seasonal use of habitat by thar in the Southern Alps of New Zealand (Forsyth, 1997).

Habitat type	Spring	Summer	Autumn	Winter
Grassland	preferred	preferred	preferred	covered in winter
Grass bluff	preferred	preferred	slightly preferred	preferred
Rock bluff	preferred	slightly avoided	preferred	preferred
Scree	avoided	avoided	avoided	avoided
Shrubland	preferred	preferred	preferred	highly preferred
Snow	avoided	avoided	avoided	avoided

Forsyth (1997) noted that the observations of chamois habitat use agreed with those of the work of Christie (1963), Clarke and Henderson (1984), and Clarke (1986). Forsyth (1997) also noted that chamois migrated to lower-altitude forests during winter, behaviour also reported by Clarke (1986).

Yockney (1997) studied the diet and distribution of chamois in the lowland forests of Westland. Rumens were collected from animals shot in the Whataroa River area and analysed for diet (Table 2.5). Yockney noted that during the early 1990s chamois have expanded their range within lowland forests on the West Coast. Yockney (1997) noted

that significant seasonal differences in the amount of grass consumed could be attributed to chamois feeding more often on grassy slips during spring.

Table 2.5 Food types of chamois in a lowland forest, West Coast, New Zealand. A total of 40 rumens were analysed from chamois shot in spring and summer (Yockney, 1997).

Food type	Mean % dry weight
Woody plants	83.24
Herbaceous plants	4.29
Grasses and sedges	7.70
Ferns	4.35
Lichen	0.28
Fungi	0.03
Mosses and Liverworts	0.11

Thar habitat relationships reveal similar patterns to those of chamois, although where the two species are sympatric differences occur (Forsyth, 1997). Burrows (1974) concluded that thar prefer sites of *Dracophyllum* shrubland and *Chionochloa* grassland, as these communities are the most heavily degraded where thar are present. Tustin (1990) noted that thar are normally found in the zone between 1400 and 1700 m. During winter north and north-east slopes are preferred as they are sunnier and are less likely to accumulate snow (Tustin, 1990). In the North Branch (Godley Valley) thar were observed to primarily use two communities, short podocarp scrubland (dominated by *Podocarpus nivalis*) and tall snow tussock (dominated by *Chionochloa* spp.) grassland. Other communities that were seasonally utilised were matagouri (*Discaria toumatou*) shrubland during spring, and short tussock grassland during spring and autumn (Tustin, 1990). The Department of Conservation (1993) management plan for thar notes that thar primarily inhabit bluff systems and adjacent subalpine shrublands and alpine grasslands. On the eastern side of the main divide of the Southern Alps, dry tussock grasslands were primarily utilised during non-winter months. In winter months thar utilised vegetation on snow-free bluffs and in higher statured shrublands. In South Westland thar used upper forest areas dominated by southern rata (*Metrosideros umbellata*), kamahi (*Weinmannia racemosa*) and in some areas silver beech (*Nothofagus menziesii*) (Department of Conservation, 1993). Parkes and Thomson (1995) noted that thar generally ate more grass than herbs or woody plants (Table 2.3). Grasses were recorded to contribute between 48% and 66% of diet dependent on area. Thar were recorded as descending to lower altitudes in early spring to take advantage of the early spring growth of introduced grasses (for example *Anthoxanthum odoratum* and *Agrostis capillaris*) (Parkes and Thomson, 1995). Forsyth (1997) recorded that male and female thar avoided areas of scree and snow (Table 2.4b). During spring and

summer male thar preferred grassland significantly more than female thar. In autumn and spring female thar selected grass bluffs significantly more than males (Forsyth, 1997). Forsyth (1997) recorded that in spring, summer and autumn all groups of thar moved to lower altitude grassland and shrubland during evening and higher altitude bluff areas during morning.

2.2.3 Habitat selection by feral goats in New Zealand.

Riney and Caughley (1959) studied the home range of a feral goat herd north of Wellington. They noted the strong influence of social organisation of the goat herd on the boundaries of individual home ranges. Home range data for a group of fifteen nannies and kids revealed an area of 550 m by 820 m (an area of approximately 45 hectares). Riney and Caughley (1959) noted that the home range of male goats was considerably larger than the 45 ha exhibited by females. Three areas were noted as sustaining high use within the home range. The vegetation of each high use area was predominantly either sheep pasture or native grass interspersed with low shrubs. High use areas were interconnected by well-used trails, the formation of which appeared related to topography (Riney and Caughley, 1959). High use areas provided the main areas for feeding requirements, as well as providing areas for fighting, mating, and sunning. Forest areas were less well utilised and appeared to provide areas for shelter (Riney and Caughley, 1959), whilst burning of areas on forest margins (farmland) produced habitat more favourable to goats. Atkinson (1964) noted that feral goats avoided bog areas and alluvial terraces, but were attracted to areas that contained large proportions of grass or salt-laden vegetation. Williamson (1975) found that feral goats grazed on grassland areas, a finding similar to that of Riney and Caughley (1959). Preference was recorded for dry, sunny, north-west and north-east facing slopes close to bluff and scrub (Williamson, 1975).

Hayward (1985) reviewed the impact of browsing mammals on forests at Isolated Hill Scenic Reserve. Hayward noted that goat densities within the reserve were higher than those of other managed conservation areas in Marlborough, and that the degree of utilisation of plant species in the browse tier (Table 2.6) was highest at Isolated Hill (average utilisation at Isolated Hill 95%, at Pelorus 35%, at Northbank Wairau 20%). Vegetation plots were established in the reserve in secondary seral forest communities dominated by *Prumnopitys taxifolia*, *Melicytus ramiflorus*, *Griselinia littoralis*,

Dodonaea viscosa which were considered to be the most seriously depleted communities by feral goat impact and habitat use.

Table 2.6 Percentage of biomass in the browse tier for plant species at Isolated Hill Scenic Reserve (after Hayward, 1985). Degree of utilisation by browsing animals was calculated by comparing the proportion of browsed to unbrowsed plants.

Browse tier species	Percentage of browse biomass	Degree of utilisation by browsing animals
Coprosma propinqua	33	97
Coprosma rhamnoides	13	88
Myrsine australis	12	99
Pennantia corymbosa	8	100
Melicytus ramiflorus	7	98
Coprosma linariifolia	7	94
Polystichum vestitum	4	99
Sophora microphylla	4	97
Coprosma crassifolia	4	84
Pseudopanax crassifolium	2	90
Carpodetus serratus	2	100
Olearia paniculata	2	71
Myrsine divaricata	1	96
Griselinia littoralis	1	100
Polystichum richardii	1	70

Mitchell *et al.*, (1987) investigated the annual diet of feral goats on the eastern slopes of Mt Taranaki (Table 2.7) and noted that collection of rumens from goats was clumped by vegetation communities. Sub-habitats (for example river-banks versus forest) were seasonally occupied by feral goats, hence diet was a seasonal reflection of habitat selection. Mitchell *et al.*, (1987) also noted that preferences for different food types would have relevance to other areas of New Zealand where those food types were present. Mitchell *et al.*, (1987) noted that future diet studies must consider the heterogeneity of vegetation because:

1) often a large variety of different vegetation communities are present in close proximity;
2) vegetation communities themselves are not homogeneous, and hence relative availability of food types can strongly affect predicted dietary preferences.

Sherley (1988) recorded that feral goats on the Auckland Islands were predominantly using coastal margins, grassed areas, and coastal rata (*Metrosideros*) forest. Sherley stated that the rata forest and two peat areas were used as "lanes" for access between preferred grassed areas. Hawes (1989) in a visit to Isolated Hill Scenic Reserve (the location of this study) recorded mean goat pellet counts for the three major catchments within the reserve (Table 2.8). Hawes reported that variability in the counts was

attributable to pellet groups being counted at different times of the year (summer for 1985, and spring for 1989), and also to error in the actual counts.

Table 2.7 Annual mean percentage volume and availability of principal food types consumed by feral goats at Mt Taranaki (after Mitchell *et al.*, 1987). Preference for food types is also indicated. Principal species are defined as those contributing greater than 2% by weight of total diet. Preference ratings are annual mean % vol/% availability or P for preferred. Preference ratings less than 1 indicate avoided food items.

Food type	Annual mean % volume	% availability	Preference
Asplenium bulbiferum	31.2	18.7	P
Weinmannia racemosa	9.4	0.88	10.711
Ripogonum scandens – vine	7.4	0.0	P
Schefflera digitata	5.7	0.21	27.362
Griselinia littoralis	5.3	0.91	5.769
Coprosma grandifolia	5.0	0.40	P
Melicytus ramiflorus	4.9	0.46	10.607
Astelia spp.	4.0	8.0	0.498
Ripogonum scandens – fruit	3.2	0.0	P
Ripogonum scandens – foliage	3.0	1.2	2.520
Lotus penduculatus	2.9	0.0	P
Coprosma tenuifolia	2.7	0.86	3.144

Table 2.8 Mean goat pellet group count frequencies for 1985 and 1989, Isolated Hill Scenic Reserve (Hawes, 1989).

Location	Average pellet group count 1985	Average pellet group count 1989	Average pellet group count overall
Isolation Catchment	27	19	23
Brian Boru Catchment	42	28	35
Average for total area	34.5	23.5	29

Parkes (1993) reviewed a wide range of data associated with feral goats in New Zealand. Average densities of feral goats for large areas were Great Barrier Island 0.3 ha^{-1}, Wairau 0.05 ha^{-1}, Mt. Egmont National Park 0.1 ha^{-1}, and West Motu River 0.1 ha^{-1}. A study by Brennan (1992) at Dinner Creek (near the Waima River, north-west of Isolated Hill Scenic Reserve) recorded densities of 0.17 feral goats ha^{-1}.

Parkes (1993) also presented dietary data for two spatially separated populations of feral goats near the Motu River (East Cape, North Island) (Table 2.9). The Motu River separated the populations; the eastern population effectively represented an invading or newly arrived population as seral species (for example *Carpodetus serratus*) were still strongly represented in the diet (Parkes, 1993). On the western side of the Motu River Parkes (1993) noted that the feral goat population consumed significantly more canopy species (for example *Weinamnnia racemosa*), suggesting that feral goats had depleted the vegetation on that side of the river. Parkes (1993) also noted that the occurrence of

the fungus *Auricularia* on the western bank was potentially an indicator of higher levels of dead wood, which Parkes suggested might have been induced through browsing.

Table 2.9 Principal food types for feral goats on opposing banks of the Motu River (Parkes, 1993). Principal species are defined as those contributing greater than 2% by weight of total diet.

Food type	East bank (Mean % of sampled dry weight)	West bank (Mean % of sampled dry weight)
Ripogonum scandens	14.8	26.1
Melicytus ramiflorus	9.0	11.7
Weinmannia racemosa	2.0	10.0
Ixerba brexioides	0.6	8.0
Auricularia polytricha	0.0	6.3
Cirsium vulgaris	1.8	4.3
Coprosma spp.	8.6	3.0
Dicksonia squarrosa	0.2	2.4
Carpodetus serratus	7.3	1.0
Clematis parviflora	5.5	1.0
Libertia ixioides	2.9	0.7
epiphytic *Asplenium* spp.	2.7	0.7
Geniostoma ligustrifolium	2.3	0.6
Coriaria arborea	3.3	0.4
Hebe salicifolia	2.6	0.3
Lotus pedunculatus	2.2	0.1

Cochrane (1994) in a study of impacts and diet at Isolated Hill Scenic Reserve remeasured New Zealand Forest Service vegetation quadrats set up in 1985 and characterised diet from the rumens of 50 feral goats (Table 2.10). Cochrane noted that feral goats were concentrating on a few plants in terms of diet, and hence that particular areas of the reserve were most affected. Cochrane (1994) also noted that the original New Zealand Forest Service arrangement of vegetation monitoring quadrats provided an incomplete picture of vegetation availability and impact of feral goats (a concern that led to this study).

Table 2.10 Principal food types for feral goats at Isolated Hill Scenic Reserve 1992-1993 (Cochrane, 1994). Principal species are defined as those contributing greater than 2% by weight of total diet.

Food type	Mean % of sampled dry weight	Frequency (%)
Griselinia littoralis	38.6	90
Monocotyledon spp.	19.3	88
Melicytus ramiflorus	12.0	76
Coprosma rhamnoides	3.7	40
Clematis spp.	2.3	18
Prumnopitys taxifolia	2.1	12

Stronge *et al.*, (1997) studied the foraging ecology of feral goats in the Mahoenui Reserve, North Island. Their study recorded bimodal peaks in feeding activity, especially in female goats (males exhibited bimodal feeding during autumn and spring, but a single peak during summer). Females grazed more often than males (females

47%, males 31%), whereas males browsed more often than females (males 13%, females 6%). Stronge *et al.*, (1997) observed that during winter the proportion of gorse in the rumens of both sexes increased substantially (Table 2.11). They noted that in part the importance of gorse was attributable to the low vegetative diversity of the area in which the goats were sampled. Stronge *et al.*, (1997) also recorded a synergistic effect between cattle and goats. Cattle were able to open up areas of impenetrable gorse, which thus improved access for goats to forage.

Table 2.11 Winter and summer diet of feral goats at Mahoenui Reserve (after Stronge *et al.*, 1997).

Food type	Male		Female	
	Winter	Summer	Winter	Summer
Grass	25%	85%	50%	70%
Gorse	70%	5%	45%	12%
Other	5%	10%	5%	18%

Males goats spent more time in standing and walking activities (Table 2.12), an allocation that reflected the poorer quality of browse intake, and thus the need to spend longer ruminating (Stronge *et al.*, 1997).

Table 2.12 Behaviour time activity budget for feral goats at Mahoenui Reserve (Stronge *et al.*, 1997).

Activity	Male	Female	Average
Feeding	44.0	53.0	48.5
Resting	28.0	25.5	26.8
Standing	15.5	10.0	12.8
Walking	8.5	8.0	8.2
Maintenance	2.7	2.7	2.7
Agonism	0.8	0.3	0.5
Other	0.5	0.5	0.5
Total	100.0	100.0	100.0

Clearly feral goats in New Zealand exhibit a variety of habitat preferences. Of importance is that few studies directly measured habitat relationships, instead many infer relationships from diet analysis or from the results of vegetative investigations. However, a number of general factors (Table 2.13) can be derived from the literature and are potentially important in determining habitat selection by feral goats. Factors can be broadly divided into physical (topography, weather, ground moisture, and aspect) and biotic (diet, salt, behaviour, and predation).

Table 2.13 Summary of physical and biotic factors considered in relation to suitable feral goat habitat.

Factor Type	Factor	Description	Literature Reference
Physical	Topography	Topography affected daily movement patterns	Atkinson, 1964
	Weather	Rain and general inclement weather induced use of vegetated areas to provide shelter	Atkinson, 1964; Riney and Caughley, 1959
	Ground moisture	Goats avoided obviously damp habitats such as bogs. Preference shown for dry areas	Atkinson, 1964; Williamson, 1975
	Aspect	Preference shown for north-west and north-east facing slopes	Williamson, 1975
Biotic	Diet	Diet can be wide ranging or relatively narrow, but always consists of a few principal plant species. Diet can differ over relatively short distances, and will differ depending on the history of exploitation of the area. Grasslands and grassland/forest boundaries often mentioned as preferred feeding areas. Burning of areas also improves habitat suitability.	Riney and Caughley, 1959; Atkinson, 1964; Hayward, 1985; Mitchell *et al.* 1987; Sherley, 1988; Brennan, 1992; Parkes, 1993; Cochrane, 1994; Stronge, 1997
	Salt	Attraction to areas with salt-laden vegetation	Atkinson, 1964
	Behaviour	Social organisation of the feral goat herd influences individual home range boundaries. "Flight" behaviour observed when being hunted.	Riney and Caughley, 1959; Brennan, 1992
	Predation	Hunting observed to make feral goats more likely to seek shelter. Hunting also suggested as a limiting factor in terms of subsequent habitat selection.	Riney and Caughley, 1959; Parkes, 1984

2.3 Experimental design and aims

The overall aim of the thesis is to characterise habitat selection by feral goats at Isolated Hill Scenic Reserve in spatial and temporal terms. Specifically the study will centre on an investigation of how vegetation structure and composition affect the relative distribution of feral goats across a series of vegetation communities. A secondary aim is to investigate whether habitat selection in feral goats is changed immediately after a major control operation.

The thesis consists of three major areas of analysis; a characterisation and description of vegetation communities present within the reserve and an associated experimental control area, analysis of feral goat habitat selection, and investigation of spatial targeting and general management of feral goat control in Isolated Hill Scenic Reserve.

The experimental design was a before/after control/impact (BACI) design using Black Angel Creek (a stream catchment located 2.5 km north of Isolated Hill) as a spatial and temporal experimental control area.

Specifically the study has the following aims:

1. to investigate how vegetation composition and structure affects feral goat habitat selection;
2. to investigate how feral goat habitat selection changes subsequent to major control programmes;
3. to investigate how habitat selection data can be used to improve control planning and operations.

To achieve these aims the following approach will be used:

1. Characterise the vegetation communities present at Isolated Hill Scenic Reserve and Black Angel Creek so as feral goat habitat selection and use can be measured. The characterisation will include:
    - identifying plants that typify the different communities;
    - measuring the percentage cover of palatable species;
    - calculating diversity indices and measuring physical factors associated with the different communities.

2. Observe and measure the habitat selection and use by feral goats of different plant communities at Isolated Hill Scenic Reserve and Black Angel Creek. This will include:
    - characterising seasonal habitat selection and use through direct observation at Isolated Hill and Black Angel Creek;
    - characterising habitat selection and use prior to a major control operation and immediately after a control operation through direct observation and the recording of faecal pellet group distribution;
    - calculating parameters for different vegetation communities that may be indicators of habitat selection and use;
    - calculating models of feral goat habitat selection and use for Isolated Hill Scenic Reserve;
    - investigating diet as a causal process for habitat selection and use.

3. Compare Department of Conservation hunting data with the recorded habitat selection of feral goats and produce simple cost models of feral goat control at Isolated Hill Scenic Reserve. Consider management of feral goats at Isolated Hill Scenic Reserve generally. This will include:
    - comparing the distribution of feral goat kills with observed feral goat habitat selection;
    - calculating a hunting difficulty index for different vegetation communities at Isolated Hill Scenic Reserve
    - formulating a simple cost analysis model for feral goat hunting at Isolated Hill Scenic Reserve
    - comparing and contrasting the differences in factors that may affect hunting efficiency (individual hunters, hunter types, season, habitat, and weather)
    - discussion of the role that habitat selection models could play in improving operational control programmes.

Chapter 3 - Vegetation of Isolated Hill Scenic Reserve and Black Angel Creek

3.0 Introduction

For habitat selection studies a clear understanding of the vegetation relationships in the area of study is paramount, particularly so when relating selection by animals to palatability of differing vegetation communities. What is meant by a vegetation community? Begon *et al.,* (1996) define a community as "an assemblage of species populations that occur together in space and time". From a botanical slant, Burrows (1990) defines a community as an "arbitrary subdivision of a continually varying pattern of species composition." Both of these definitions represent a body of theory that believes that vegetation is a continuum that can be divided into recognisable communities only arbitrarily (Barbour *et al.*, 1980). Even within relatively homogeneous units of vegetation there are subtle differences. Hence, it can be assumed that the vegetation of an area is the result of two forces, the fluctuating process of plant recruitment, and a variable environment (Barbour *et al.*, 1980).

The contrasting view is of a community as a consistent floristic composite (Miles, 1979). This body of theory proposes that similar areas of vegetation growing under similar environmental conditions and with similar histories of environment and plant migration are often very alike in composition (Barbour *et al.*, 1980). Thus a community is an assemblage of vegetation that repeats itself in space and time (Miles, 1979), and can be individually identified. However, this view still requires an arbitrary division as to the exact spatial boundaries of a community.

Both views of a community require that an arbitary decision be made at some stage, however, in terms of a spatially heterogeneous environment the former continuum view is more applicable as it recognises the more complex situation where vegetation is a continuously varying and intergrading mosaic. Further, multivariate techniques, such as

classification and ordination, can aid investigation of communities by providing objective quantitative measures of the similarity or dissimilarity of measured vegetation. For this study a vegetation community is defined as:

Vegetation community: an arbitrary subdivision of a continually variable and intergrading plant species composition.

The study areas (Isolated Hill Scenic Reserve and Black Angel Creek) have had botanical descriptions of the vegetation communities present (Williams and Druce 1979, Williams, 1982; Hayward, 1985; Breese *et al.*, 1986; Druce and Williams, 1989; O'Brien, 1993; Cochrane, 1994). In the wider Southern Marlborough context vegetation studies have been completed in the Seaward Kaikoura Ranges (Wraight, 1967; Wardle, 1971) and the Inland Kaikoura Ranges (Druce and Williams, 1989; Williams 1989). All of the studies have been descriptive in nature, although Hayward (1985) and Cochrane (1994) provided quantitative data in support of their descriptions.

Hayward (1985) implemented a monitoring programme in secondary seral forest of Isolated Hill Scenic Reserve using standard New Zealand Forest Service vegetation quadrats. The quadrats were specifically intended to quantify the impact of feral goats in specific forest types. Thirty-two standard quadrats were established, including three exclosures. The quadrat locations were subjectively chosen to allow assessment of feral goat impacts on secondary seral forests, and of whether hunting programmes could reduce feral goat numbers sufficiently to allow the development of an understorey through successful recruitment of seedlings.

Cochrane (1994) re-measured the quadrats as a part of a study investigating feral goat diet in Isolated Hill Scenic Reserve. The study focused upon five different vegetation communities (Hall's totara, Kanuka, Matai, Broadleaf, and Red Beech) and the relationship between vegetation changes and the diet of feral goats. The study allowed development of a vegetation change model and noted specific impacts that feral goats were having on elements within the vegetation communities. Cochrane (1994) noted limitations in the New Zealand Forest Service design, in particular the emphasis upon a limited number of vegetation communities within Isolated Hill Scenic Reserve.

Hence this chapter aims to characterise and describe the vegetation communities present at Isolated Hill Scenic Reserve and Black Angel Creek, identify the plants that typify the communities, and measure vegetative cover of different species within each community. A review of the general characteristics of the study area is also provided. Specifically the aims are:

1. define recognisable vegetation communities at Isolated Hill Scenic Reserve and Black Angel Creek;
2. record and measure the dominant plant species present and their cover in each community;
3. calculate indices of species diversity, dominance and evenness, vegetative cover, and calculate physical aspects (slope, aspect, altitude) for each community for use in habitat modelling.
4. create a vegetation map to allow estimation of community areas and classification of kill sites (Chapter 5).

3.1 Study Areas

Despite a history of 140 years of pastoralism in Southern Marlborough, substantial areas of semi-indigenous vegetation remain in areas where land clearance has proved economically disadvantageous or physically impossible. It is in these areas that landholders and regulatory bodies face many issues relating to introduced mammalian pests. Two areas were chosen for the study of habitat selection by feral goats (see Chapter 4 for a full description of the experimental design) (Fig. 3.1).

The areas chosen for the study (Isolated Hill Scenic Reserve and Black Angel Creek) are located in tributaries of the Waima River (Fig. 3.1). Isolated Hill Scenic Reserve is an area of indigenous and semi-indigenous vegetation administered by the Department of Conservation, whilst Black Angel Creek is an area of semi-indigenous and pastoral vegetation and forms part of Blue Mountain Station.

3.1.1 History of Isolated Hill Scenic Reserve and Black Angel Creek

A comprehensive history for Isolated Hill Scenic Reserve can be read in Cochrane (1994). This section will present a short history of the area with specific reference to the study

areas and the impact of feral goats in the area. The area has a history of use by Maori, in particular for the hunting of moa in the scrublands of the area (L. Buick pers. comm.).

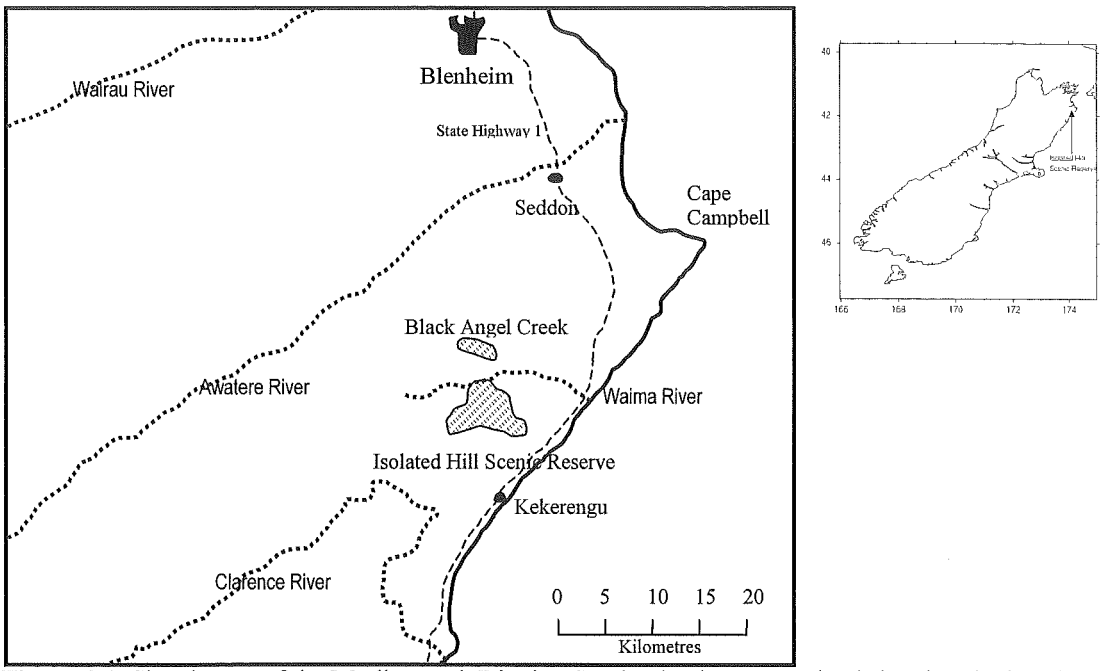


Figure 3.1 Sketch map of the Marlborough District, South Island, New Zealand showing the location of the study areas (Isolated Hill Scenic Reserve and Black Angel Creek) in Southern Marlborough. The smaller figure shows the location of Isolated Hill Scenic Reserve within the South Island.

The general area of Flaxbourne/Kekerengu (which encompasses both study areas) has a recorded European history beginning in 1846 with the arrival of the explorer Frederick Weld. European settlement quickly followed the explorations of Frederick Weld, and by the early 1870s merino sheep farming was well established in the Flaxbourne/Kekerengu area (Kennington, 1972). Isolated Hill Scenic Reserve was formally recognised in 1924 when it was classified as a Reserve and Sanctuary for native birds. Unfortunately, this classification under the Scenery Preservation Act 1908 protected not only the indigenous fauna, but also introduced mammals such as feral goats, which by this time had colonised the reserve (Cochrane, 1994). The Reserve's status did not change until 1979 when it was reclassified as a Scenic Reserve under the Reserves Act 1977. Despite this late reclassification of the reserve, control of feral goats had been ongoing since the 1960s (Cochrane, 1994), by the New Zealand Forest Service. In 1987 statutory control of the reserve was passed to the Department of Conservation, which has not only maintained programmes of control of introduced mammalian pests (possums and goats), but has expanded animal control generally by expanding the track and hut network within the reserve. This has improved the efficacy of control within the reserve by improving living conditions for staff, and by improving access between catchments.

Black Angel Creek forms a part of Blue Mountain Station, a high country station that since 1963 has been owned by D.L. Buick. Blue Mountain Station is a high country sheep run farmed since the early 1900s, and during this time has been modified as a part of pastoral management programmes. Before European settlement and use of the Blue Mountain area, extensive burning of forestlands has been attributed to Maori (L. Buick pers. comm.).

3.1.2 Geology and soils

The two study areas differ considerably in geology and soil. Isolated Hill Scenic Reserve is an area of Cretaceous mudstone overlain by deposits of Amuri Limestone (Druce and Williams, 1989). The limestone is up to 750 m in depth, and extends in a broad band west - east through the reserve. Completing the geological mosaic of the reserve are sulfurous argillites, sandstones, and mudstones (Hayward, 1985). Of particular interest are the areas of mudstone, which are prone to slumping and mass movement. On areas surrounding Isolated Hill Scenic Reserve the geology and soils are also variable. Torlesse greywackes of the lower Cretaceous are found along the lower reaches of the Waima River (Breese *et al.*, 1986), and the soils are Amuri and Kaitoa steepland soils and Kekerengu hill soils (Breese *et al.*, 1986).

In Black Angel Creek the geology is predominantly Greywacke-based (O'Brien, 1993), whilst the soils are similar to those from the coastal areas of Isolated Hill – Kaitoa steepland soils and Kekerengu hill soils.

3.1.4 Introduced animal pests

A number of introduced animal pests are present in both study areas. At Isolated Hill Scenic Reserve Cochrane (1994) observed feral goats, feral pigs, red deer, brushtail possums, and rabbits. Also recorded in the reserve are chamois (M. Brennan pers. comm.). During the period of this study, hares were observed in the reserve, as was a single hedgehog. Sheep and cattle occasionally impinge upon the reserve.

Black Angel Creek has a similar assemblage of introduced animals. Feral goats, feral pigs, red deer, brushtail possums, and rabbits are all present in the area. Red deer and feral pigs are not controlled as they are viewed as an important resource for recreational

hunting. Feral goats, brushtail possums, and rabbits are all actively controlled in the area. A significant difference between Black Angel Creek and Isolated Hill Scenic Reserve is the presence of farmed sheep in the former area.

3.2 Methods used for vegetation study and analyses

3.2.1 Vegetation field methods

Vegetation quadrats were measured in both Isolated Hill Scenic Reserve and Black Angel Creek. Quadrats were randomly located along transect lines which followed magnetic bearings. Start points for the transects were randomly located along the base of river and stream valleys . These start points were then used as the start of transects within the two areas (except in two cases where the start points were located in terrain that was not navigable). The quadrats were located along the transect by pacing a random number of steps from quadrat to quadrat. Transects were continued until landscape features (for example ridgelines) ended.

Three sizes of quadrat were used. Quadrats within forested areas were 20 m by 20 m; quadrats measured in combined grass/scrubland associations were 10 m by 10 m; and quadrats measured in grassland alone were 2 m by 2 m. At each quadrat site the following site descriptions were recorded; physiography, slope, altitude, rock cover, bare soil cover, drainage, and signs of browse from introduced mammalian pests. Physiography was recorded as one of four different forms; ridge, face, gully, or terrace. Slope was recorded using an Abney level that was sighted at a down-slope object at a height of 1.6 m. Aspect was measured using a compass and corrected for magnetic declination. The barometric pressure altimeter used (for calculating altitude of vegetation quadrats) was calibrated against known heights daily. Rock cover and bare soil cover were estimated visually. Drainage was classified visually as good, medium, or poor. Visual signs of mammals were recorded, in particular footprints, faeces and browsed palatable plant species.

A list of all plant species present within the quadrat was recorded. Data were then collected (using visual estimation) for the cover of each species in each of four tier classes: seedling (0-0.3 m), sapling (0.3-2 m), sub canopy (2-5 m), and canopy (≥5 m). Where species were lianes or epiphytic in nature, a separate tier class was recorded.

Percentage cover was recorded in each tier using a cover score system of 1-6. These were 1, < 1%; 2, 1-5%; 3, 6-25%; 4, 26-50%; 5, 51-75%; 6, 76-100%.

3.2.2 Vegetation analysis

3.2.2.1 Data summary

The data were analysed using PC-RECCE (Hall, 1992), an MS-DOS programme which allows analysis of data collected from reconnaissance-style vegetation plots. It features routines for classification, ordination, and data summary and allows for progressive analysis of data sets (all programmes listed below are modules within PC-RECCE).

Summary data for quadrat groups was calculated using RECSUM. It summarises environmental factors and also allows detailed analysis of vegetation associated with each of the quadrat groups. Environmental factors analysed in this work were altitude, aspect, slope, physiography, and drainage. The factors were summarised as means and standard errors. Three different vegetation summaries were used in this work: layer diagrams, which summarises tier heights and species cover; frequency, which summarises species frequencies and tier percentage frequencies; and cover, which summarises species cover by tier class.

3.2.2.2 Classification

CLUSTER was used to classify vegetation data with polythetic agglomerative clustering. Data for all species were used to calculate similarity between quadrat pairs, and vegetation communities were progressively built up in a hierarchical form. The form of linkage used in these analyses was the Group Average Linkage method (see Kent and Coker, 1992 for details). Cluster output was generated in the form of a dendrogram, with plot linkages and similarities outlined.

TWINSPAN was used as another form of cluster analysis. It differs from cluster in that it is a divisive (as opposed to agglomerative) form of clustering. Twinspan uses indicator species to show key differences between vegetation types (Gauch, 1982). Default settings were used in these analyses.

3.2.2.3 Ordination

Ordination analyses of the vegetation data were completed using CANOCO (ter Braak, 1988). PC-RECCE was used to compile Cornell Condensed Format files that were then analysed via CANOCO. All ordinations utilised detrended correspondence analysis, which is an indirect form of gradient analysis. Downweighting of rare species was used as a method of reducing the effect that rare species might have in distorting the analyses (ter Braak, 1988). Species that are less than 20% of the frequency of the commonest species are downweighted in proportion to their abundance. Environmental factors were subsequently correlated with the position of vegetation quadrats on axes 1 and 2 using Spearman rank correlations.

3.2.2.4 Vegetation maps

Vegetation distribution maps for Isolated Hill Scenic Reserve and Black Angel Creek were prepared using aerial photographs, ground reconnaissance and topographical maps. Aerial photography work was completed by Mr K. Nicolle from the Department of Natural Resources Engineering, Lincoln University, Canterbury. Photographs were taken on 4 May, 1996, at an altitude of 2450 m (amsl). The camera used was a Pentax 645, with a 55 mm lens attached. Multiple photographs were taken with 30% overlap between exposures. The position of the aircraft for each pass was noted using a GPS system. The exposures were developed using a standard colour process, and were provided in final format as multiple 5-inch by 7-inch colour prints (final scale approximately 1:15 000). The photographs were then placed together in a montage, and vegetation communities interpreted (classification and ordination techniques were used to determine communities). Identified vegetation communities were then plotted onto a 1:25 000 scale topographical map of Isolated Hill Scenic Reserve and Black Angel Creek. Vegetation distributions were then checked using ground reconnaissance.

3.2.2.5 Diversity indices

Diversity indices were used to quantify differences between community types that were independent of actual species composition. Five different methods were used – three index based, and two graph based.

Taxonomic species richness, the Berger-Parker index and Margalef's diversity index were the three different diversity indices used. Taxonomic richness was a count of the number of different taxa described for each of the vegetation communities. The Berger-Parker index is a dominance type index, and is calculated as the proportion of all individuals that the single most abundant taxon occupies. The index takes the form (Magurran, 1988):

$$d = \frac{N_{max}}{N} \qquad \text{Eq. 3.1}$$

where: N_{max} = number of individuals in the most abundant taxon
N = the total number of individuals

Magurran (1988) noted that diversity measures could use cover abundance as a replacement for the number of individuals (N), however, she cautioned that biased results were possible, especially where non-linear systems were used. In this study cover abundances have been converted into mid point percentages reducing the likelihood of biased results.

The Margalef's index is a diversity index (evenness index) and takes the form (Magurran, 1988):

$$D_{Mg} = \frac{(S-1)}{\ln N} \qquad \text{Eq. 3.2}$$

where: S = the number of species recorded
N = the total number of individuals

The two graphical methods were species rank-abundance plots and tier rank-abundance plots. The first plot ranks species from commonest to rarest, and plots them against their relative abundances. The second method considers species richness in each of the tiers present in each of the vegetation communities.

3.2.2.6 Separation of Isolated Hill Scenic Reserve and Black Angel Creek

The analysis of the vegetation at Isolated Hill Scenic Reserve and Black Angel Creek was done separately for two reasons. First, the substrate for both areas is different. At Isolated Hill Scenic Reserve a mixture of limestone and Cretaceous mudstone is present, whereas at Black Angel Creek Greywacke is the substrate. The second reason for the separate analysis is that both areas have experienced different management regimes.

Isolated Hill Scenic Reserve has been managed since early this century as a reserve while Black Angel Creek has been managed for pastoral values. Hence, results for both areas are presented separately.

3.3 Results - the vegetation of Isolated Hill Scenic Reserve

3.3.1 The vegetation of Isolated Hill Scenic Reserve - Overview

Analysis of the vegetation data at Isolated Hill Scenic Reserve shows 11 recognisable vegetation communities. Cluster analysis (Fig. 3.2) shows the differentiation of the 125 quadrats into eleven vegetation communities. At the 0.04 level of similarity differentiation is made between forest and non-forest vegetation types. At this level there are clearly major differences in the flora of the two distinctive groups. For the non-forest vegetation types the next differentiation is at the 0.10 level of similarity where the bluffs and screes community is divided from the other non-forest communities. At 0.20 similarity a division is made between subalpine and grassland communities. Finally, at the 0.35 level of similarity the improved grassland and grass – scrubland communities are divided.

For the forest type communities, the first level of division occurs at 0.22 similarity. At this level a division is made on the basis of high levels of cover of *Podocarpus hallii* in the red beech and Hall's totara communities, and the strong presence of *Prumnopitys taxifolia* and *Melicytus ramiflorus* in the other forest type communities. The Red Beech and Hall's Totara communities are divided on the basis of the presence of *Nothofagus fusca* in the former, and *Myrsine divaricata* in the latter. Broadleaf is the next community to be identified (at 0.25 similarity) on the basis of the presence of *Cassinia leptophylla* and *Dodonaea viscosa*. The presence of both of these species indicates the more open nature of the canopy in this community. The next division occurs at 0.26 similarity, when the kanuka community is divided from the remaining three. The key indicator at this level was the dominance of *Kunzea ericoides* in this community. The mahoe - titoki is the next to be divided (0.35 similarity), the presence of *Alectryon excelsus* being the key determinant in the division. The final division occurs at 0.40 similarity and separates the matai community from the mountain beech community. This division appears at first unusual because of the relatively distinct nature of the two vegetation communities involved. However, at Isolated Hill Scenic Reserve the two communities often bound one

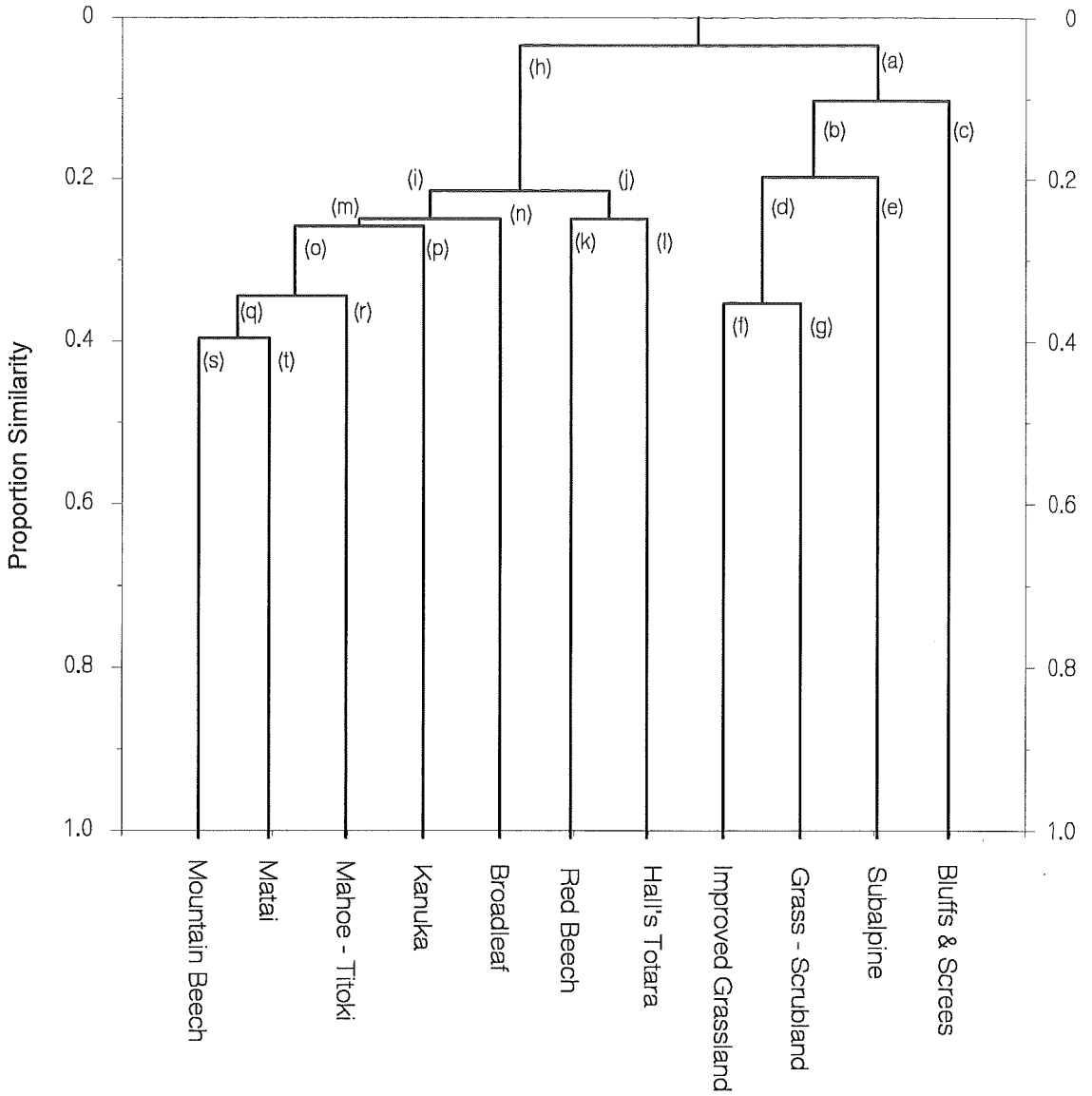


Figure 3.2 Community classification using an agglomerative clustering technique showing the eleven communities identified for Isolated Hill Scenic Reserve. Community similarity is shown on the y axis. Indicator species groups are indicated by bracketed letters *e.g.* (a). Indicator species groups are (a) *Chionochloa* sp.; (b) *Anthoxanthum odoratum, Poa cita*; (c) *Dodonaea viscosa, Echium vulgare*; (d) *Holcus lanatus, Taraxacum* spp.; *Trifolium* spp; (e) *Aciphylla* sp.; (f) *Dactylis glomerata*; (g) *Cassinia leptophylla*; (h) *Coprosma rhamnoides*, or *Griselinia littoralis*, or *Melicytus ramiflorus*, or *Myrsine australis*, or *Uncinia* spp.; (i) *Prumnopitys taxifolia*, or *Melicytus ramiflorus*;(j) *Podocarpus hallii*; (k) *Nothofagus fusca*; (l) *Myrsine divaricata*; (m) *Coprosma linariifolia, Carpodetus serratus, Asplenium* spp.; (n) *Cassinia leptophylla, Dodonaea viscosa*; (o) *Prumnopitys taxifolia, Melicytus ramiflorus*, (p) high cover scores for *Kunzea ericoides*; (q) *Coprosma crassifolia, Coprosma rhamnoides*; (r) *Alectryon excelsus, Myoporum laetum*; (s) *Cyathodes fraseri, Nothofagus solandri*; (t) *Coprosma crassifolia, Olearia paniculata.*

another, and the encroachment of key species from both communities into one another leads to the level of similarity apparent here.

Figure 3.3 shows the site ordination plot from a detrended correspondence analysis (DCA) using cover abundance data. Figure 3.4 shows the site ordination of a DCA using presence –absence data. Four environmental factors were found to be significantly correlated (see Fig. 3.5) with the position of species and hence sites on axes 1 and 2 of the ordination.

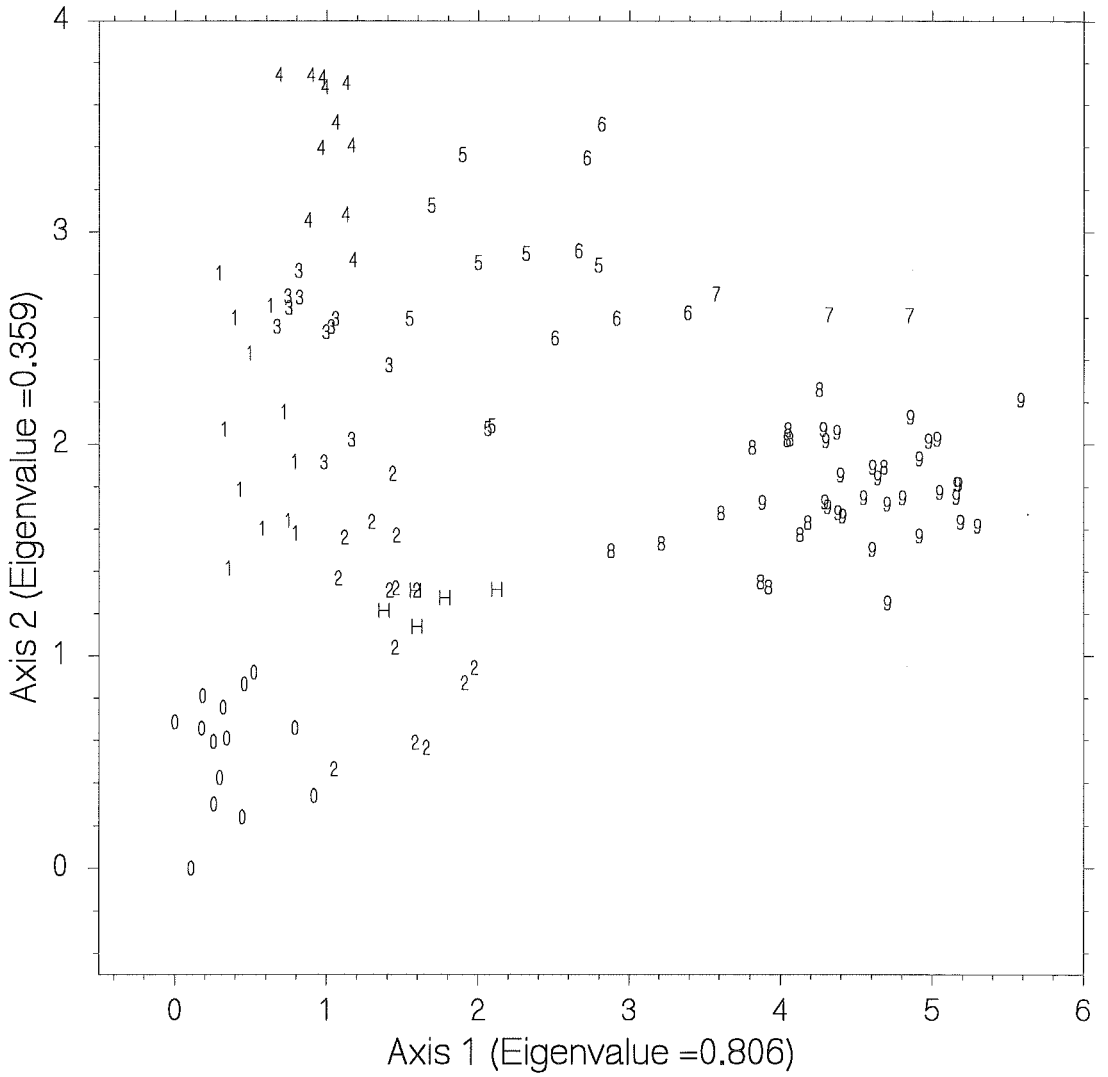


Figure 3.3 Ordination of Isolated Hill Scenic Reserve vegetation quadrats using Detrended Correspondence Analysis. Data is in cover format. Numbers indicate vegetation communities; 0 Red Beech; 1 Mountain Beech; 2 Kanuka; 3 Matai; 4 Mahoe - Titoki; 5 Broadleaf; 6 Bluffs and Screes; 7 Subalpine; 8 Grass – Scrubland; 9 Improved Grassland; H Hall's Totara. The sum of all eigenvalues is 6.606, hence axis 1 explains 12.2% of the variation in the data, while axis 2 explains 5.4% of the variation.

Altitude increases from left to right along axis one, hence, the subalpine and improved grassland communities are higher altitude communities. The slope of sites increases as axis 1 increases from left to right, and as axis 2 increases from bottom to top. North-south aspect increases towards the top of axis 2. Hence, communities on the bottom of the ordination (in particular grass/scrubland) tend to be south facing, whilst communities in the upper left of the diagram (mountain beech, matai, mahoe – titoki) tend to be north facing. Drainage is positively correlated with both axes 1 and 2. Hence poorly drained sites typify the red beech community, while very well drained sites typify communities in the top right (for example bluffs and screes). The presence - absence and cover ordinations did not clearly separate some of the identified vegetation communities. The presence – absence ordination (Fig. 3.4) was particularly poor at differentiating between the mountain beech, kanuka, matai, and Hall's totara communities. The ordination also

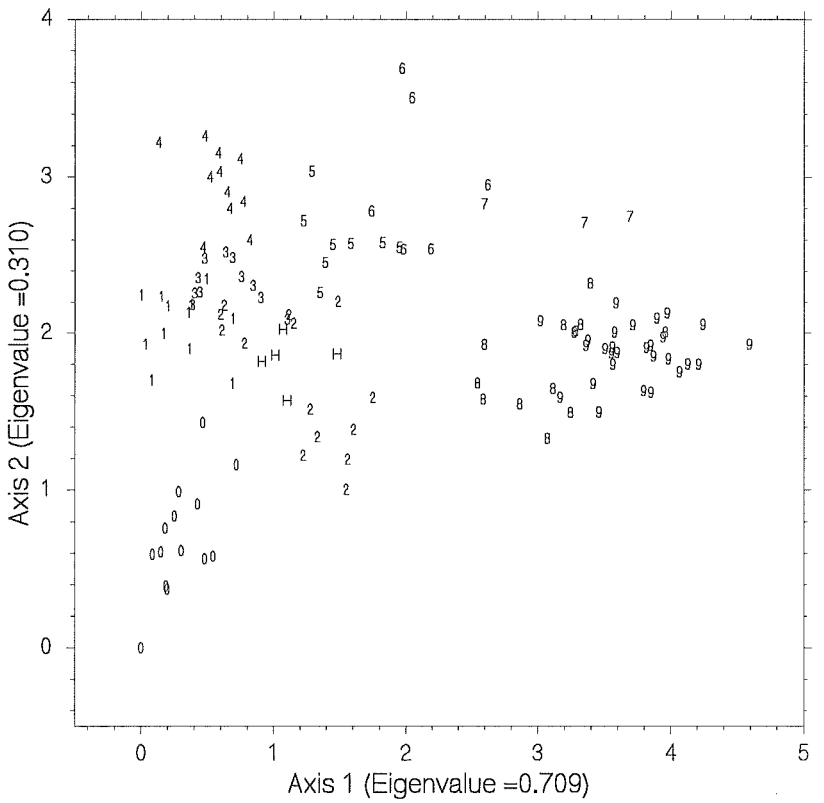


Figure 3.4 Ordination of Isolated Hill Scenic Reserve vegetation quadrats using Detrended Correspondence Analysis. Data is in presence – absence format. Numbers indicate vegetation communities; 0 Red Beech; 1 Mountain Beech; 2 Kanuka; 3 Matai; 4 Mahoe - Titoki; 5 Broadleaf; 6 Bluffs and Screes; 7 Subalpine; 8 Grass – Scrubland; 9 Improved Grassland; H Hall's Totara. The sum of all eigenvalues is 5.104, hence axis 1 explains 13.9% of the variation in the data, while axis 2 explains 6.1% of the variation.

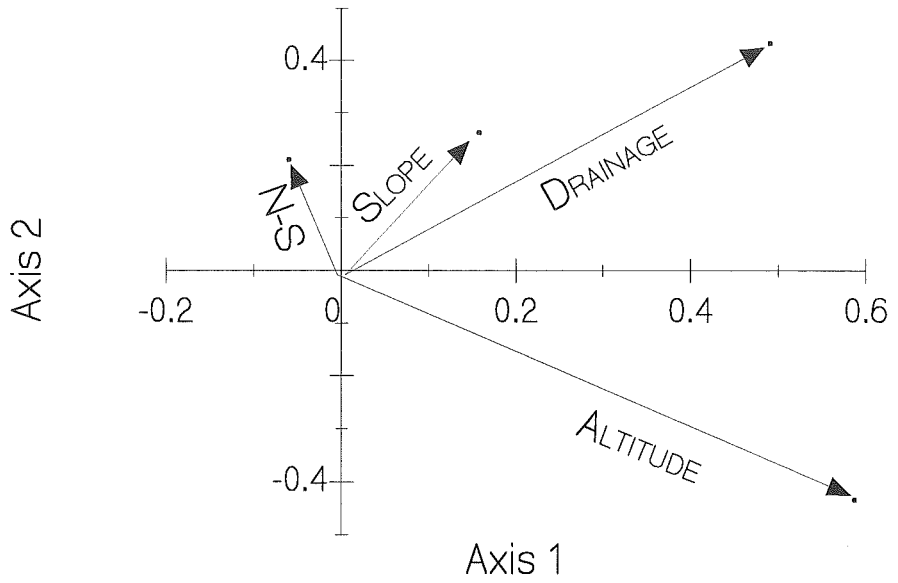


Figure 3.5 Diagram of Spearman rank correlations between significant environmental variables and position of plots on axes 1 and 2 of the cover ordination (A). For (A) altitude is significantly correlated with axis 1 ($P<0.001$), in a positive direction, and axis 2 ($P<0.001$) in a negative direction. The cosine of aspect, *i.e.* north-south is significantly correlated with axis 2 ($P<0.01$), in a positive direction. Slope is significantly correlated with axis 2 ($P<0.01$) in a positive direction and with axis 1 ($P<0.05$), also in a positive direction. Drainage is positively correlated with both axes ($P<0.001$ for both axes). Spearman rank correlations for the presence absence ordination produced similar correlations for all environmental variables, except for the positive correlation between slope and axis 2, which is significant to $P<0.001$.

poorly differentiated between the improved grassland and grass/scrubland communities. The cover ordination differentiated between the forest communities better, however it was still poor at differentiating between the two grassland communities. This may reflect a strong species overlap between the two communities.

The rank abundance plots (Fig. 3.6) elucidate the taxonomic diversity and dominance of individual species within each of the communities. Two groups are apparent from the analysis, communities with a wide range of species and approximately 8-10 taxa which occur at greater than 1% abundance, and communities where one or small numbers of taxa dominate and diversity is limited. The latter group consists of Hall's totara, bluffs and screes, and subalpine communities. All three exhibit dominance by a single taxon or a few taxa and low diversity in comparison to the other communities. This may be

accounted for by abiotic factors in the case of case of bluffs and screes and subalpine communities, where only a few species are able to adapt well to the conditions inherent in both. In the case of the Hall's totara community, interspecific competition is the key factor in accounting for the dominance of a single species, *Podocarpus hallii*.

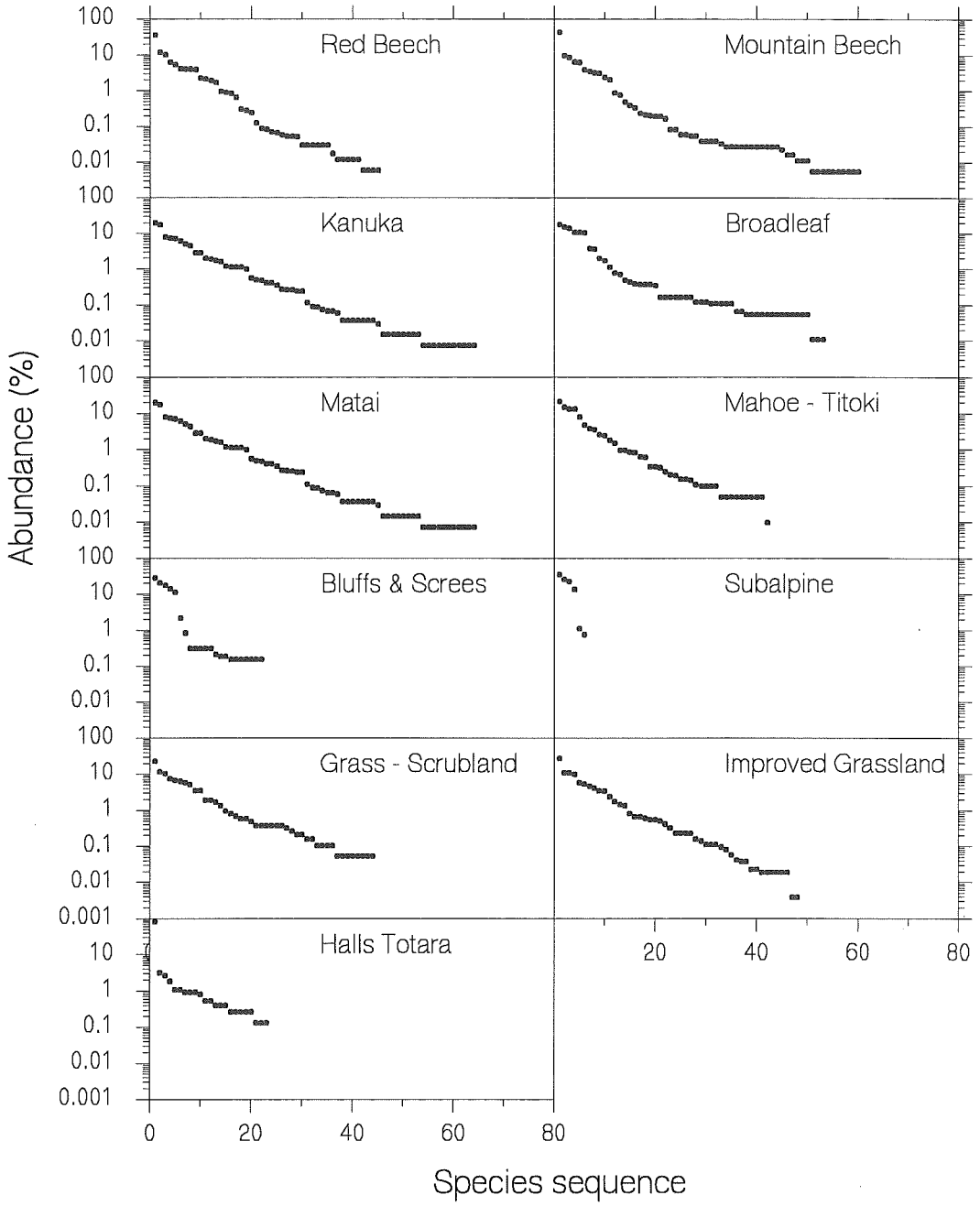


Figure 3.6 Species rank abundance plot for the 11 vegetation communities identified at Isolated Hill Scenic Reserve. Percentage of total vegetative cover was used as the measure of abundance. The x-axis represents the number of species present in each community.

Tier structure diversity (Fig. 3.7) shows the diversity of the five different tiers recorded as a part of the study. Three broad groups are recognised; those that are physiognomically "forest" types, those that are taxonomically depauperate (subalpine and bluff and scree communities), and grassland communities which lack floristic components in the 5m+ and liane tiers.

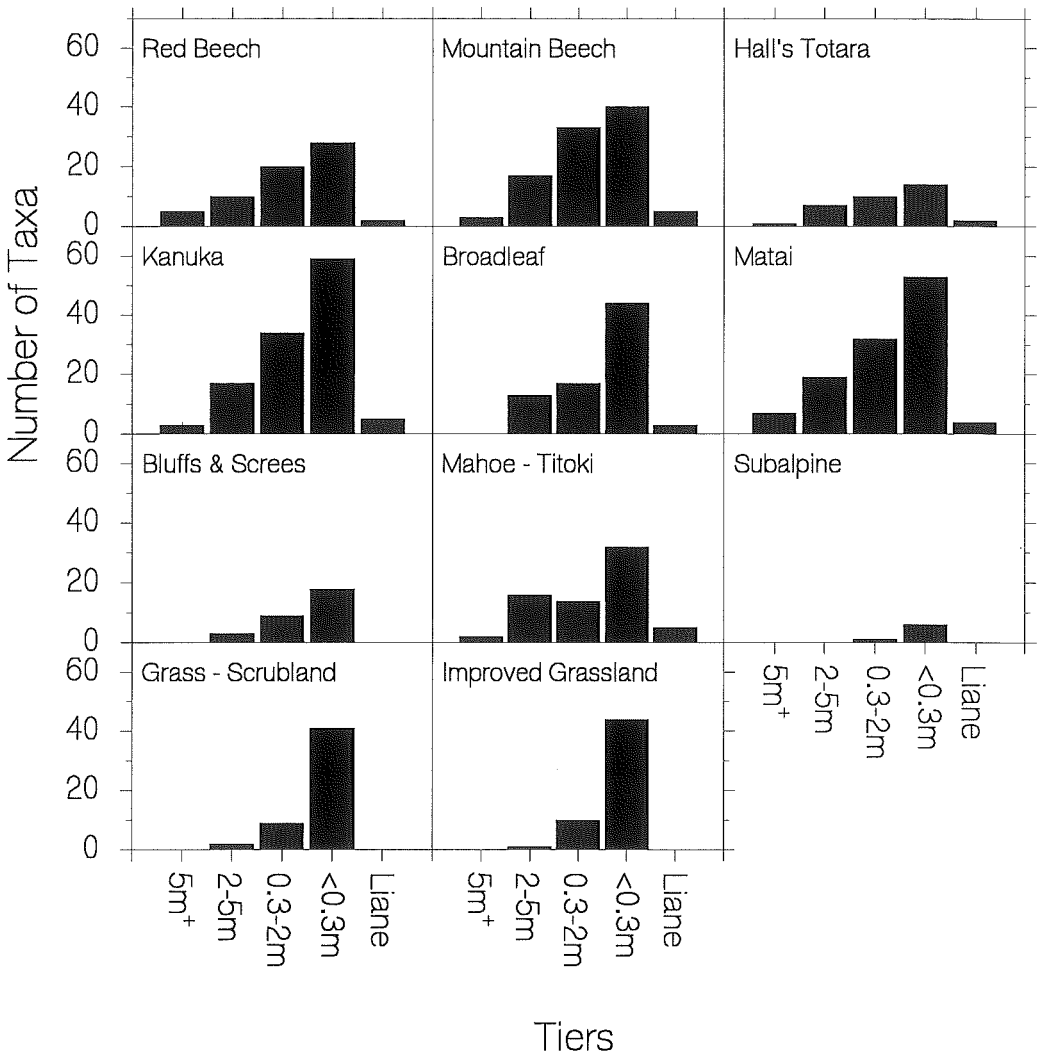


Figure 3.7 Tier structure diversity for the 11 identified vegetation types in Isolated Hill Scenic Reserve. Five different tiers were recognised for this study: canopy and emergents (5 m and above); sub-canopy (2-5 m); browse zone (0.3-2 m); seedling tier (0-0.3 m); and lianes and epiphytic tier (any plant growing as a liane or epiphytically on other plant species). Three broad diversity types can be recognised from the graphs. The three diversity types are vegetation communities with most tiers represented (that is vegetation types which are physiognomically "forest" types); vegetation communities that are floristically depauperate (at Isolated Hill Scenic Reserve this includes the sub-alpine and bluff/scree communities); and vegetation communities which lack representation in the 5m+ and liane tiers (in this case the two grassland based communities).

Community indices (Table 3.1) can be divided into three types; diversity indices that consider taxonomic diversity only, a diversity index that incorporates proportional abundance, and finally the cover index which is unrelated to diversity or abundance of individual taxa, but is instead a measure of cover of all tiers in each community. Diversity only indices (taxonomic richness and Margalef's index) indicate a continuum from the matai community (22.09 and 4.44 respectively) through to the subalpine community (4.67 and 0.80 respectively) (Table 3.1).

Table 3.1 Taxonomic richness, Margalef's index, Berger-Parker dominance index and cover index for the 11 identified vegetation communities at Isolated Hill Scenic Reserve. The mean value for each community is presented along with one standard error. Taxonomic richnesss is the mean number of species per plot. Cover index is the summed cover values for all tiers and is an index of vegetation density.

Community	Taxonomic richness	Margalef's index	Berger-Parker index	Cover index
Bluffs and Screes	6.83 (± 2.12)	2.18 (± .70)	0.54 (± 0.13)	38 (± 23.72)
Broadleaf	16.25 (± 1.41)	2.87 (± 0.23)	0.53 (± 0.05)	115 (± 14.28)
Grass – Scrubland	14.08 (± 0.92)	3.31 (± 0.23)	0.35 (± 0.05)	77 (± 10.48)
Hall's Totara	11.60 (± 0.87)	2.49 (± 0.13)	0.81 (± 0.03)	72 (± 11.44)
Improved Grassland	11.17 (± 0.80)	2.32 (± 0.17)	0.53 (± 0.04)	89 (± 6.52)
Kanuka	16.00 (± 1.68)	2.96 (± 0.32)	0.52 (± 0.04)	162 (± 17.40)
Mahoe-Titoki	14.64 (± 1.01)	3.02 (± 0.20)	0.39 (± 0.06)	94 (± 9.35)
Matai	22.09 (± 1.62)	4.44 (± 0.32)	0.68 (± 0.07)	129 (± 12.01)
Mountain Beech	19.40 (± 1.48)	3.82 (± 0.33)	0.52 (± 0.06)	135 (± 11.80)
Red Beech	17.80 (± 1.25)	3.53 (± 0.24)	0.51 (± 0.05)	122 (± 11.50)
Subalpine	4.67 (± 0.33)	0.80 (± 0.13)	0.44 (± 0.07)	132 (± 41.72)

The next type of index considers the proportional dominance of the most common taxa within the community. The Berger-Parker index is used, in its non-reciprocal form. Simply stated, as the index increases so to does the proportional dominance of the most common taxa. Two communities (Hall's totara and matai) have very high proportional dominance by the most common taxa. The next group ranges from bluffs and screes (0.54) to red beech (0.51), and includes six communities. There is little difference between them, although the value for the bluffs and screes community should be interpreted cautiously due to the large standard error associated with it. The final group of three communities (subalpine, mahoe-titoki, and grass/scrubland) exhibit lower proportional dominance by individual taxa. In the case of the subalpine community this result is strongly affected by its particularly low diversity, and the equal cover of the taxa

recorded. The vegetative cover index ranges from 38 units for bluffs and screes to 162 units for the kanuka community. Mountain beech has the next highest cover score at 135, while Hall's totara is the second to lowest at 72.

Comparison of the rank ordering of vegetation communities using the different indices is made in Figure 3.8. Little change occurs between the two diversity indices, however substantial differences are apparent for the dominance index and the vegetative cover index.

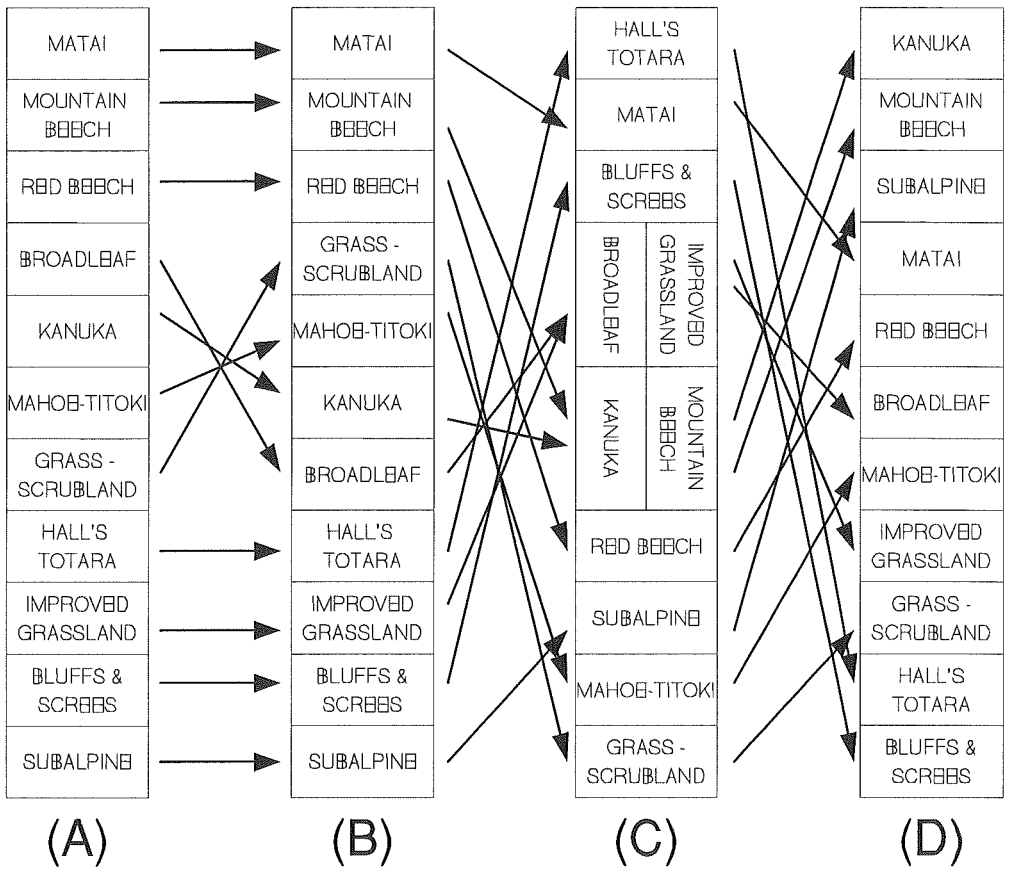


Figure 3.8 Diagramatic representation of the rank of communities for four different community indices. The four indices are (A) taxonomic richness, (B) Margalef's index, (C) Berger-Parker index, and (D) cover index. Community rank was decided by mean values for each of the indices. Differences in rank do not necessarily indicate statistically significant differences.

A vegetation map was drawn for the distribution of the eleven different vegetation communities at Isolated Hill Scenic Reserve (Fig. 3.9). The map reveals that many of the vegetation communities are fragmented throughout the reserve, although two communities, red beech and mountain beech form large swathes within the reserve.

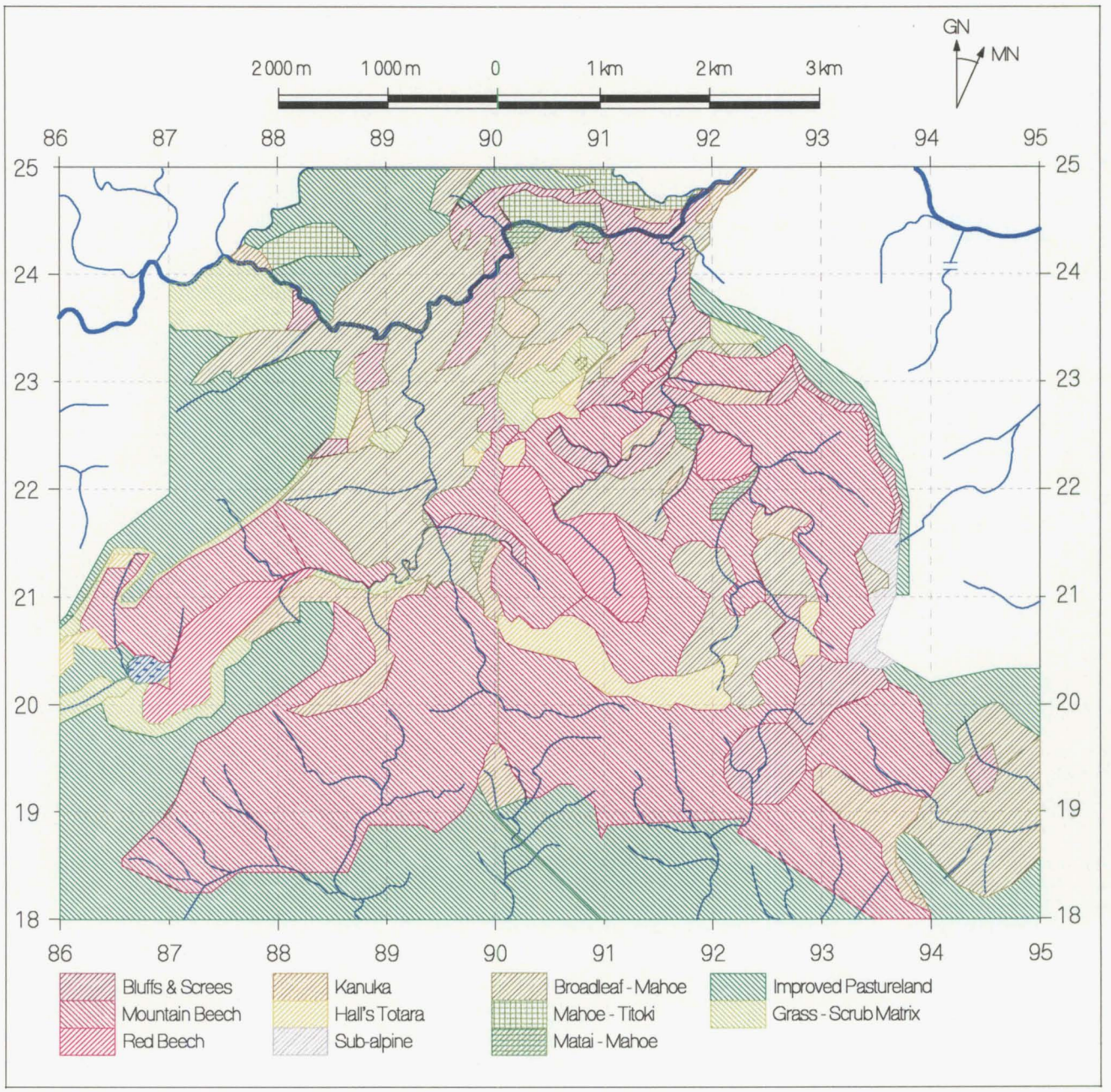


Figure 3.9 Vegetation Map of Isolated Hill Scenic Reserve. The map was prepared using aerial photographs taken in May 1996. Vegetation boundaries were plotted onto 1:25 000 scale topographical maps then transferred onto a computer graphics programme. Base topographical maps, 1:50 000 scale, are NZMS 260 P29 & Q29, Grassmere, Edition 1, 1985, and NZMS 260 P30, Clarence, Edition 1, 1990. Black and White aerial photographs are available from Aerial mapping New Zealand, SN 8533, F40, F41, F42, F43, G13, and G14 (1:25 000, 1985 and 1986), whilst colour aerial photographs used for the preparation of this map may be viewed at the Nelson Conservancy Office, Department of Conservation.

3.3.2 The vegetation communities – 1. Red beech

The red beech community occurs in an altitudinal range of 600-800 m (average altitude of 694 m). Aspect varies between south-east and north-west, although most quadrats had a southerly aspect. The community occurs on slopes of between 5° and 35° with the average slope at 14.1° ± 3.1° (1 S.E.). Drainage in this community is poor in comparison with the other communities found at Isolated Hill Scenic Reserve.

The total number of species recorded for this community was 45 (key species, that is species with a cover of > 1%, are listed in Table 3.2). The canopy of this community is dominated by *Nothofagus fusca*, although *N. solandri* is also common. Occasional *Podocarpus ferruginea* trees are present, as are *P. hallii* and *Kunzea ericoides*. In the sub-canopy layer *N. fusca* is less dominant with *Carpodetus serratus* and *P. hallii* more common. *Coprosma foetidissima* appears in this tier, and can be considered as one of the indicator species of this vegetation type. In the browse layer *Pseudowintera colorata* is dominant, with *N. fusca* and small-leaved *Coprosma* species also abundant. *Elaeocarpus hookerianus*, another indicator species is also present. The seedling layer is characterised by abundant *N. fusca*, *Uncinia* spp., *C. serratus*, *Griselinia littoralis*, *Blechnum discolor*, *Polystichum vestitum*, *Microlaena avenacea*, and *Nertera depressa* plants. Two liane taxa are also common – *Rubus* spp., and *Parsonsia heterophylla*.

Table 3.2 Percentage cover and percentage occurrence of plant species in the Red Beech community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=14).

Species	Mean percentage cover	Percentage frequency
Nothofagus fusca	43.5	100
Pseudowintera colorata	14.2	85
Nothofagus solandri	12.3	64
Podocarpus hallii	7.6	93
Kunzea ericoides	6.5	14
Aristotelia serrata	5.0	93
Prumnopitys ferruginea	4.8	29
Coprosma microcarpa	4.8	79
Coprosma rhamnoides	4.7	93
Myrsine australis	2.7	7
Leucopogon fraseri	2.6	64
Coprosma linariifolia	2.3	71
Pseudopanax crassifolium	2.0	79
Cyathodes juniperina	1.1	14
Griselinia littoralis	1.1	79

3.3.3 The vegetation communities – 2. Mountain beech

Mountain beech communities occur between 350 and 500 m in the reserve (average altitude 415 m). Aspect was evenly distributed with quadrats present in all aspect classes. Similarly, there was a wide range of slopes with quadrats recording slopes between 5° and 45° (average slope 22.7°, ± 3.2° (1 S.E.)). Two-thirds of the mountain beech quadrats were on face sites, the other third of quadrats were evenly distributed between gully and terrace sites. No ridge sites were recorded. Most sites recorded good drainage, while the remainder were sites which had a medium level of drainage.

The total number of taxa recorded for this vegetation community was 60 (key species are listed in Table 3.3). This vegetation community is dominated at all tier levels by *Nothofagus solandri*. In the canopy *Prumnopitys taxifolia* was regularly present, although its percentage cover was never close to that of *N. solandri*. In the subcanopy *Melicytus ramiflorus*, *Cyathea dealbata*, *Kunzea ericoides*, *Myrsine australis*, *Carpodetus serratus*, and *Aristotelia serrata* are all present. Of particular interest was the presence of *Cyathea dealbata* in 50% of the quadrats. In some quadrats *C. dealbata* dominated the subcanopy, browse and seedling tiers. Common seedling tier species were *N. solandri*, *Mycelis muralis*, *Polystichum vestitum*, *Coprosma rhamnoides*, *C. linariifolia*, *Cyathodes juniperina* and *C. fraseri*. *Clematis* sp. and *Rubus* spp. were present in the liane tier.

Table 3.3 Percentage cover and percentage occurrence of plant species in the Mountain Beech community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=12).

Species	Mean percentage cover	Percentage frequency
Nothofagus solandri	66.5	92
Melicytus ramiflorus	14.8	100
Coprosma rhamnoides	12.8	83
Cyathea dealbata	9.7	50
Prumnopitys taxifolia	9.4	83
Kunzea ericoides	5.9	25
Myrsine australis	5.4	92
Coprosma linariifolia	4.8	58
Carpodetus serratus	4.7	100
Aristotelia serrata	3.6	58
Helichrysum aggregatum	3.1	50
Cortaderia sp.	1.3	17
Pennantia corymbosa	1.1	50

3.3.4 The vegetation communities – 3. Hall's Totara

The Hall's totara community was recorded as occurring between 800 and 900 m (average altitude 844 m). Aspect was southerly, three of the five quadrats occurred in the range 135° to 225°. Slopes were distributed between 25° and 35° (average slope 27.4°, ± 1.5° (1 S.E.). All of the quadrats were recorded on face sites. Drainage at all quadrats was recorded as good.

The total number of taxa recorded for this community was 24 (key species are listed in Table 3.4). The community is dominated by *Podocarpus hallii*, which forms a dense canopy cover. Similarly, in the subcanopy tier *P. hallii* dominates. Other species that are present in the subcanopy tier include *Griselinia littoralis*, *Myrsine divaricata*, and *Pittosporum eugenioides*. The browse tier is dominated by *Myrsine divaricata* and *Coprosma rhamnoides*. Other common species in the browse tier were *Carpodetus serratus*, *Coprosma linariifolia*, and *C. propinqua*. In the seedling tier *Polystichum vestitum* predominates, with *Asplenium* spp., *Acaena* spp., *M. divaricata*, *C. rhamnoides*, *Poa cita*, *Holcus lanatus*, *Mycelis muralis*, *Urtica ferox*, *Uncinia* spp., and *C. linariifolia* also common. In the liane tier *Clematis* sp. and *Rubus* spp. were present.

Table 3.4 Percentage cover and percentage occurrence of plant species in the Hall's Totara community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=5).

Species	Mean percentage cover	Percentage frequency
Podocarpus hallii	60.5	100
Myrsine divaricata	2.4	100
Coprosma rhamnoides	2.0	60
Polystichum vestitum	1.4	80

3.3.5 The vegetation communities – 4. Kanuka

The kanuka community occurs in a broad altitudinal range from 500 to 900 m (average altitude of 658 m). It has a wide aspect range although the majority of quadrats (14 from 19) have a westerly aspect. The community has a wide slope range with the average slope being 24.9° ± 3.6° (1 S.E.) and the range being 5° to 55°. The community is found primarily on face sites, with a few quadrats found on ridge and terrace sites. No Kanuka community quadrats were recorded in gully sites. The recorded drainage was almost entirely good with only one of the nineteen quadrats recording medium drainage.

A total of 73 taxa were recorded for this community (key species listed in Table 3.5). The community is characterised by a *Kunzea ericoides* canopy. In the subcanopy *K. ericoides* also dominates, with occasional *Nothofagus solandri* and *Griselinia littoralis* plants present. In the browse zone *Helichrysum aggregatum* is the dominant plant with *Coprosma rhamnoides* also abundant, while *N. solandri*, *Coprosma colensoi*, *Coprosma linariifolia* and *Cyathodes juniperina* are present in lesser numbers. The browse zone is characteristically dense in this community, making passage except along established animal tracks difficult. The seedling tier is dominated by *Uncinia* spp., *H. aggregatum*, *G.littoralis*, and *Blechnum* spp. Of particular interest in the seedling tier was the presence of large numbers of *G. littoralis*, and *Melicytus ramiflorus* seedlings and the single occurrence of a *Coprosma grandifolia* seedling. In the liane tier *Rubus* spp. and *Clematis* sp. were regular occurrences, with *Parsonsia* spp. rarer, and *Tupeia antarctica* (a mistletoe) particularly rare.

Table 3.5 Percentage cover and percentage occurrence of plant species in the Kanuka community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=14).

Species	Mean percentage cover	Percentage frequency
Kunzea ericoides	55.5	93
Helichrysum aggregatum	24.9	64
Coprosma rhamnoides	15.2	86
Nothofagus solandri	9.6	30
Griselinia littoralis	7.4	86
Coprosma colensoi	7.0	36
Coprosma linariifolia	6.5	86
Uncinia sp.	4.3	79
Cyathodes juniperina	3.3	43
Cyathodes fraseri	3.3	36
Olearia paniculata	1.8	43
Polystichum vestitum	1.5	50
Coprosma propinqua	1.4	43
Pittosporum eugenioides	1.4	29
Coriaria arborea	1.1	7

3.3.6 The vegetation communities – 5. Broadleaf

The broadleaf vegetation community occurs at an altitudinal range of 250 – 750 m (average altitude of 468 m). Most of the quadrats were recorded at between 400 and 600 m. Seven of the eight quadrats had a westerly aspect; one site faced south. The community was recorded growing on slopes between 15° and 45° (average slope 26.8°,

± 4.1° (1 S.E.). Broadleaf vegetation was recorded as growing on face and ridge sites only. In all cases, the drainage was good.

The total number of species described for this community was 53 (see Table 3.6 for key species). The canopy of this community lacks the height of the other communities described thus far, and is restricted to below five metres. It is dominated by a mixture of hardwood species including *Griselinia littoralis*, *Melicytus ramiflorus*, *Kunzea ericoides*, *Myoporum laetum*, *Dodonaea viscosa*, and *Myrsine australis*. The browse layer of this community has *K. ericoides*, *Cassinia leptophylla*, *Coprosma propinqua*, *Senecio monroi*, and *Podocarpus totara* present. *C. leptophylla* and *K. ericoides* are the most abundant taxa in this tier. In the seedling tier *C. leptophylla* and *Poa cita* are abundant species. *Libertia ixioides* is also common, as is *G.littoralis*. Introduced grasses such as *Holcus lanatus* and *Anthoxanthum odoratum* are abundant, while other introduced species such as *Rosa rubiginosa*, *Linum catharticum*, *Hieracium* sp. are also present. In the liane tier *Clematis* spp. are abundant, *Rubus* spp. are common, while *Parsonsia* sp. are uncommon. One plant of *Tupeia antarctica* was also recorded.

Table 3.6 Percentage cover and percentage occurrence of plant species in the Broadleaf community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=8).

Species	Mean percentage cover	Percentage frequency
Griselinia littoralis	20.6	88
Melicytus ramiflorus	18.0	63
Kunzea ericoides	16.4	38
Cassinia leptophylla	12.4	100
Myoporum laetum	12.4	75
Dodonaea viscosa	12.0	75
Coprosma propinqua	4.4	63
Myrsine australis	4.3	38
Senecio monroi	2.3	13
Podocarpus totara	2	25

3.3.7 The vegetation communities – 6. Matai

The matai vegetation community has an altitudinal distribution of 250 – 650 m (average altitude of 426 m). Aspect for the community is distributed between SSE and NNE. No sites were recorded in a true easterly direction. Slopes varied between 0° and 35°, with the average at 20.2° ± 3.7° (1 S.E.). Face sites were strongly represented in terms of

physiography, with ridge and terrace sites have a lesser representation. No sites were recorded in gullies. Drainage at all sites was good.

The total number of taxa recorded for this community was 64 (for key taxa see Table 3.7). The canopy tier of this community is dominated by *Prumnopitys taxifolia*. Other species present in the canopy are *Kunzea ericoides*, *Griselinia littoralis*, and *Podocarpus totara*. In the subcanopy tier *Olearia paniculata* and *Melicytus ramiflorus* are most common; less common species are *Carpodetus serratus*, *Myrsine australis*, *K. ericoides*, *Pittosporum tenuifolium*, *Sophora microphylla*, and *Myoporum laetum*. In the browse tier *Olearia paniculata* and *Sophora microphylla* are common. Also present are *Coprosma linariifolia*, *C. colensoi*, *C. propinqua*, *C. rhamnoides*, *Pseudopanax crassifolium*, *Helichrysum aggregatum*, *M. australis*, and *Myoporum laetum*. In the seedling tier *Uncinia* spp. predominate, with *Mycelis muralis* and *G. littoralis* seedlings also widespread. *M. ramiflorus* while not as widespread is also common. Ferns are represented by *Polystichum vestitum* and *Asplenium* spp., which are common in the community. Three liane taxa are represented; *Parsonsia* spp., *Clematis* spp., and *Rubus* spp.

Table 3.7 Percentage cover and percentage occurrence of plant species in the Matai community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=11).

Species	Mean percentage cover	Percentage frequency
Prumnopitys taxifolia	24.7	100
Olearia paniculata	21.6	82
Sophora microphylla	9.7	82
Kunzea ericoides	9	36
Griselinia littoralis	8.7	100
Melicytus ramiflorus	7.6	91
Podocarpus totara	6.2	18
Coprosma linariifolia	5.4	73
Uncinia spp.	3.5	100
Myrsine australis	2.5	55
Coprosma rhamnoides	2.3	91
Carpodetus serratus	2.1	91
Myoporum laetum	2.0	27
Dodonaea viscosa	1.5	18
Nothofagus solandri	1.4	18
Asplenium spp.	1.2	55

3.3.8 The vegetation communities – 7. Mahoe – Titoki forest

The mahoe – titoki vegetation community has a lower altitudinal distribution than the other communities. The altitudinal range in which it occurs is 200 – 450 m (average altitude of 269 m). Aspect is distributed throughout the compass, although most sites tended towards a northerly distribution. Slope varied between 5° and 35°, with the average slope 22.4° ± 4.0° (1 S.E.). Physiography tended towards face sites (6), with ridge sites (4), and terrace sites (1) also represented. No gully sites were recorded. All sites had good drainage.

The total number of taxa recorded for the community was 42 (for key taxa see Table 3.8). The canopy of this community is different from other communities in that it often had *Prumnopitys taxifolia* and *Podocarpus totara* trees present as emergents above the *Melicytus ramiflorus* and *Alectryon excelsus* canopy. Also present in the canopy – subcanopy tier were *Myrsine australis*, *Griselinia littoralis*, *Myoporum laetum*, *Dodonaea viscosa, Pennantia corymbosa*, *Carpodetus serratus*, and *Coprosma linariifolia*. In the browse tier *Olearia paniculata* and *P. corymbosa* were predominant, with *A. excelsus*, *C. linariifolia, M. australis*, and *P. totara* also commonly present. Less common components in the browse tier include *Aristotelia serrata*, *D. viscosa*, *Cassinia leptophylla*, *Coprosma areolata*, *C. propinqua*, *C. rhamnoides*, *Helichrysum aggregatum*, and *Pseudopanax crassifolium*. In the seedling tier *Mycelis muralis* was abundant, as were seedlings of *P. corymbosa*. *Uncinia* spp. plants were common, as were *Acaena* spp. and *Urtica ferox* plants. In the liane tier *Clematis* spp., *Rubus* spp., and *Parsonsia* spp. were recorded. *Tupeia antarctica* was also recorded as was *Phymatosorus diversifolius* growing epiphytically.

Table 3.8 Percentage cover and percentage occurrence of plant species in the Mahoe - Titoki community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=11).

Species	Mean percentage cover	Percentage frequency
Prumnopitys taxifolia	20.1	82
Melicytus ramiflorus	13.8	100
Podocarpus totara	12.4	82
Alectryon excelsus	12.2	73
Olearia paniculata	7.3	46
Myrsine australis	4.4	64
Griselinia littoralis	3.6	55
Rubus spp.	3.4	64
Mycelis muralis	2.5	100
Myoporum laetum	2.3	55
Urtica ferox	1.7	36

3.3.9 The vegetation communities – 8. Bluffs and Screes

The altitudinal range of this community type is 200 – 1000 m (average altitude 430 m). Five of the six quadrats had northerly aspect, only one was recorded facing south. Slopes for the community varied between 35° and 55° (average slope 43.4°, ± 4.1° (1 S.E.)). Physiographically, bluff sites did not fit well the descriptions used in this study, however they were classified as ridge sites. Screes were classified as slope sites. The drainage at all sites was defined as good.

The total number of taxa recorded for this vegetation community was 22 (key species are listed in Table 3.9). The dominant species of this community is a Marlborough limestone endemic, *Gentiana astonii*. *Dodonaea viscosa* was the next most dominant species, with other common species being *Echium vulgare*, *Poa cita*, *Cassinia leptophylla*, and *Pachystegia insignis*.

Table 3.9 Percentage cover and percentage occurrence of plant species in the Bluff and Scree community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=6).

Species	Mean percentage cover	Percentage frequency
Gentiana astonii	15.5	67
Dodonaea viscosa	11.2	83
Echium vulgare	9.6	83
Poa cita	7.8	50
Cassinia leptophylla	6.2	33
Pachystegia insignis	1.2	33

3.3.10 The vegetation communities – 9. Subalpine

This vegetation community is not well represented in the sampling and hence results must be considered tentative. The altitudinal range for this community in Isolated Hill Scenic Reserve is 900 – 1000 m (average altitude of 950 m). The three sites all had a south-southwest aspect (mean aspect of 211°). The slopes for this community were all 35°. Drainage for all quadrats was good.

The total number of taxa described for this community was six (Table 3.10 lists all species). The community is dominated by *Poa cita* (this may be partially due to the proximity – approximately 100 m – of the quadrats to high altitude pastoral land) and by a

Chionochloa species. *Aciphylla* sp. is also common. The three other components of the community were *Anthoxanthum odoratum*, *Coprosma propinqua*, and a *Phormium* species.

Table 3.10 Percentage cover and percentage occurrence of plant species in the Subalpine community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=3).

Species	Mean percentage cover	Percentage frequency
Poa cita	46.7	100
Chionochloa sp.	34.2	67
Aciphylla sp.	30.0	100
Anthoxanthum odoratum	18.5	100
Coprosma propinqua	1.5	67
Phormium sp.	1.0	33

3.3.11 The vegetation communities – 10. Grass - Scrubland

The grass – scrubland community occurs at altitudes of between 650 and 1150 m (average altitude 943 m). All compass aspects were represented in the quadrats of this community. Slopes for the community varied between 5° and 35° with the average slope 21° ± 4.0° (1 S.E.). Physiographically, only ridge and face sites were recorded. The drainage at all sites was classified as good.

The number of plant taxa recorded for this community was 44 (key species are listed in Table 3.11). In this community five grass species constitute 42.8% of all vegetation cover. The key grass species is *Agrostis capillaris*, with the remaining ranked as follows *Holcus lanatus*, *Poa cita*, *Anthoxanthum odoratum*, *and Dactylis glomerata*. The tier 2 - 5 m comprises two species only, *Leptospermum scoparium* (which is the more common) and *Podocarpus hallii*. The browse tier (0.3 - 2 m) is dominated by *Cassinia leptophylla*, with other species being *Coprosma parviflora*, *Leptospermum scoparium, Cyathodes juniperina, Melicytus alpinus*, *Nothofagus solandri*, *Coprosma propinqua*, *Discaria toumatou*, and *P. hallii*. The seedling tier is as mentioned dominated by grass species, although herbaceous such as *Taraxacum* spp., *Wahlenbergia albomarginata*, *Rumex acetosella*, and *Acaena* sp. while not contributing greatly in terms of cover, are still common. Of interest from a grassland conservation perspective *Hieracium* sp. makes an appearance (0.4% of total vegetation cover).

Table 3.11 Percentage cover and percentage occurrence of plant species in the Grass – Scrubland community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=12).

Species	Mean percentage cover	Percentage frequency
Agrostis capillaris	17.7	42
Holcus lanatus	9.3	92
Poa cita	8.1	83
Blechnum penna-marina	5.9	42
Leptospermum scoparium	5.3	33
Anthoxanthum odoratum	5.0	75
Leucopogon colensoi	4.6	25
Cassinia leptophylla	4.0	83
Dactylis glomerata	2.7	50
Trifolium sp.	2.7	92
Discaria toumatou	1.5	17
Lycopodium volubile	1.5	17
Moss spp.	1.3	25
Taraxacum sp.	1.0	83

3.3.12 The vegetation communities – 11. Improved Grassland

The improved grassland community occurs at altitudes between 650 and 1050 m (average altitude 795 m). The community is represented in all compass aspect classes. Slopes for the community vary between 0° and 45°, with the average slope 22.2° ± 2.5° (1 S.E.). Twenty-four of the quadrats were face sites, while four were on ridges, and one was a gully site. Twenty-eight of the sites had drainage classified as good, one site had medium drainage.

The total number of taxa recorded for the community was 48 (key taxa are listed in table 3.12). As for the grass – scrubland community monocotyledon species dominate with seven species forming 56% of the total vegetative cover. These species (in order of greatest to least cover) are: *Dactylis glomerata, Chionochloa* sp., *Holcus lanatus*, *Agrostis capillaris*, *Lolium perenne*, *Poa cita*, and *Anthoxanthum odoratum*. Unlike the previous community where *A. capillaris* was the most abundant monocotyledon, in this community *D. glomerata* is the most abundant. In the tier class 2 – 5 m, *Kunzea ericoides* is the only species present. In the browse tier (0.3 – 2 m) *Discaria toumatou* and *Cassinia leptophylla* are the most abundant species. Also present are *Coprosma propinqua*, *Cyathodes juniperina*, *Podocarpus hallii*, *Pimelea* sp., *Leptospermum scoparium*, *Urtica ferox*, *K. ericoides*, and *Coprosma rhamnoides*. In the seedling tier (0 – 0.3 m) common

herbaceous species are *Taraxacum* sp., *Stellaria* sp., *Cardamine* sp., *Wahlenbergia albo-marginata*, *Acaena* sp., *Muehlenbeckia* sp., and *Helichrysum bellidioides*.

Table 3.12 Percentage cover and percentage occurrence of plant species in the Improved Grassland community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=29).

Species	Mean percentage cover	Percentage frequency
Dactylis glomerata	24.2	97
Discaria toumatou	9.7	45
Chionochloa sp.	9.7	66
Holcus lanatus	8.8	59
Trifolium sp.	5.2	90
Agrostis capillaris	4.7	55
Cassinia leptophylla	4.2	35
Lolium perenne	3.7	14
Kunzea ericoides	3.1	10
Poa cita	3.0	45
Anthoxanthum odoratum	2.1	17
Geranium sp.	1.5	59
Moss sp.	1.3	10
Cardamine sp.	1.2	34

3.4. Vegetation of Black Angel Creek

3.4.1 Vegetation of Black Angel Creek – overview

Analysis of the Black Angel Creek study area vegetation data identifies five vegetation communities. Cluster analysis (Fig. 3.10) shows the differentiation of the 25 quadrats into the five vegetation communities. Divisions are made at 0.10 similarity, 0.15, 0.18 and 0.22. At the 0.10 level the subalpine community is recognised as being distinct from the other four vegetation types. The next division recognizes mountain beech as a community. The final three communities are grassland, kanuka, and scrub – grassland. The grassland community had a particularly high level of adventive species present within it, reflecting the invasive nature of many of these species. Of interest are the species in common for the kanuka and scrub – grassland communities, in particular, the presence and cover of *Coprosma propinqua*, *Dactylis glomerata*, and *Kunzea ericoides* in both communities. The closer relation between these two communities reflects the absence of taxa such as *Cirsium* sp. and *Achillea millefolium*. The division level of the kanuka community must be viewed cautiously due to the low sample number.

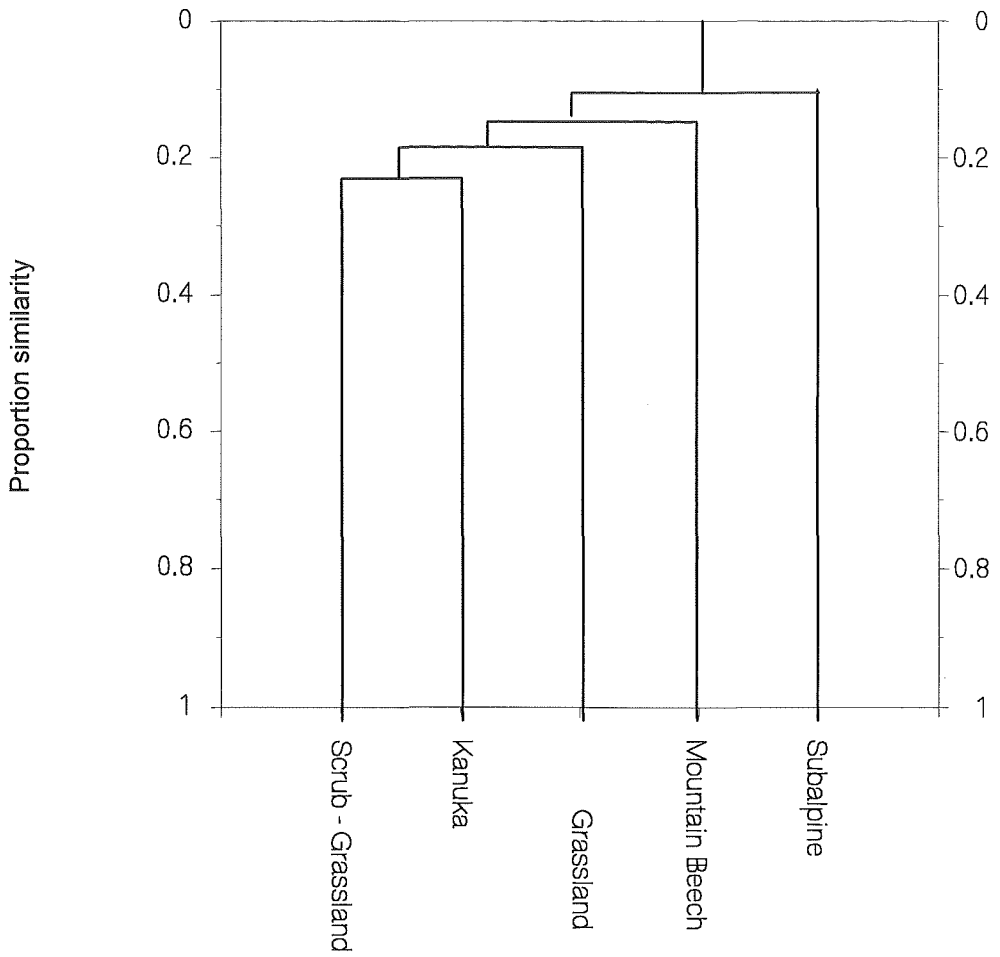


Figure 3.10 Community classification using cluster showing the five communities identified for the Black Angel Creek study area. Indicator species groups are noted by bracketed letters *e.g.* (a). Indicator species groups are: (a) *Poa cita*, and *Celmisia* sp. (b) *Anthoxanthum odoratum*, (c) *Nothofagus solandri*, (d) *Cassinia leptophylla* and *Dactylis glomerata*, (e) *Cirsium* sp. and *Achillea millefolium*, (f) *Kunzea ericoides* and *Anthoxanthum odoratum*, (g) *Pseudopanax arboreus* and high *Kunzea ericoides* cover, (h) *Anthoxanthum odoratum*, *Coprosma propinqua*, and *Cassinia leptophylla*.

Figure 3.11 shows the site plot from a detrended correspondence analysis of the 25 quadrats recorded in Black Angel Creek. A separate presence/absence ordination plot is not presented as little difference in the ordering of communities was observed between the two data analyses. Clear separation can be observed between the five communities, although the placement of the kanuka community should again be viewed cautiously due to the low sample number. Figure 3.12 represents a Spearman rank correlation between the axes one and two placements of the sites and environmental data. Three environmental variables were found to have significant correlations with at least one detrended correspondence analysis axis. The position of sites on axis 1 was positively correlated with increasing altitude. Hence, higher altitude communities are found on the right of the ordination diagram (Fig. 3.11), lower altitude on the left. The cosine of aspect

(that is north-south component) was found to be significantly correlated with axis 2 values. Hence, northern facing communities are located towards the bottom of the ordination diagram, southern facing communities towards the top. Slope was also significantly correlated with axis 2 values (and with the cosine of aspect). Steeper sites are the north facing communities, whilst less steep communities tend to be southern facing. The site ordination clearly differentiates between the five communities. This is due to the wide altitudinal range present in Black Angel Creek, and the exclusive nature of many of the species recorded within the area (for example *Nothofagus solandri* was exclusively found in the mountain beech community, *Achillea millefolium* was exclusively found in the grassland community). The restricted distribution of species within the study area probably also represents the effects of long-term grazing management.

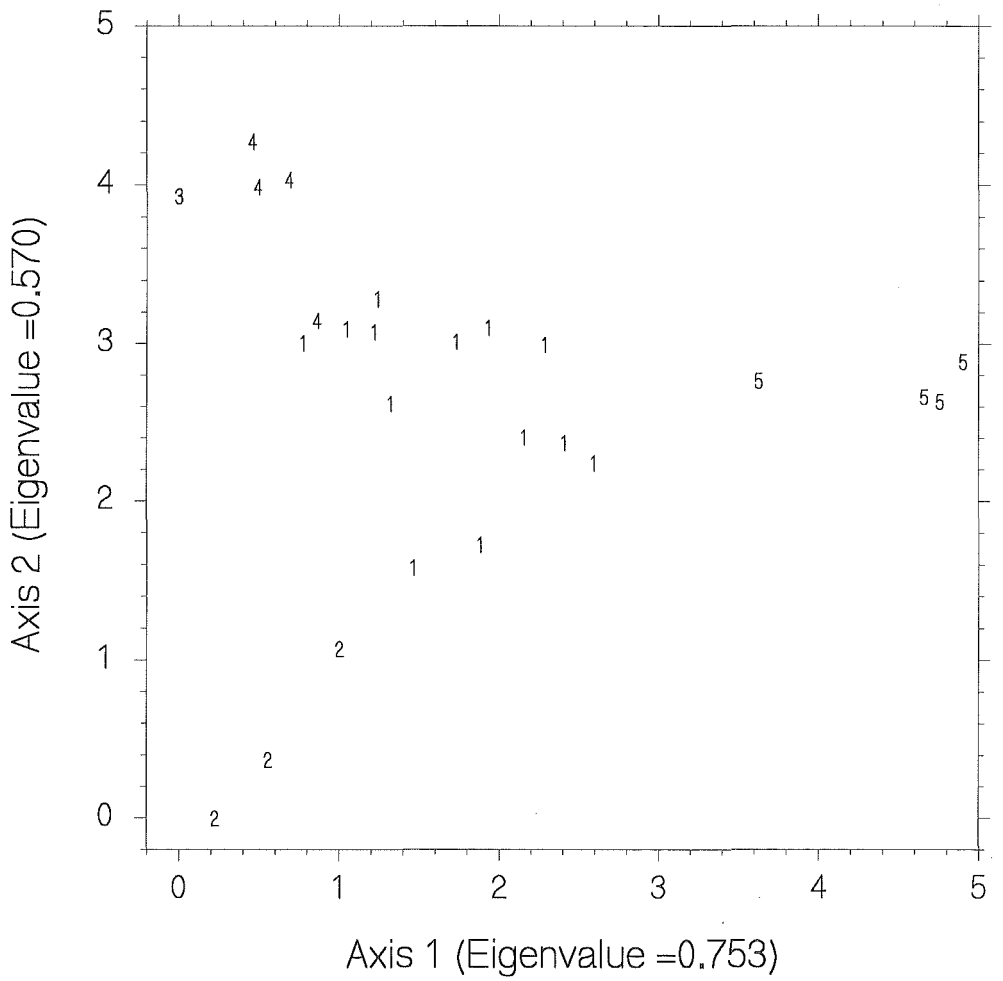


Figure 3.11 Plot ordination for Black Angel Creek vegetation data. The five denoted vegetation communities are: 1 Scrub – grassland matrix, 2 Grassland, 3 Kanuka, 4 Mountain Beech, 5 Subalpine. The total of all eigenvalues was 6.210 (the first two axes explain 21.3% of the variation in the data).

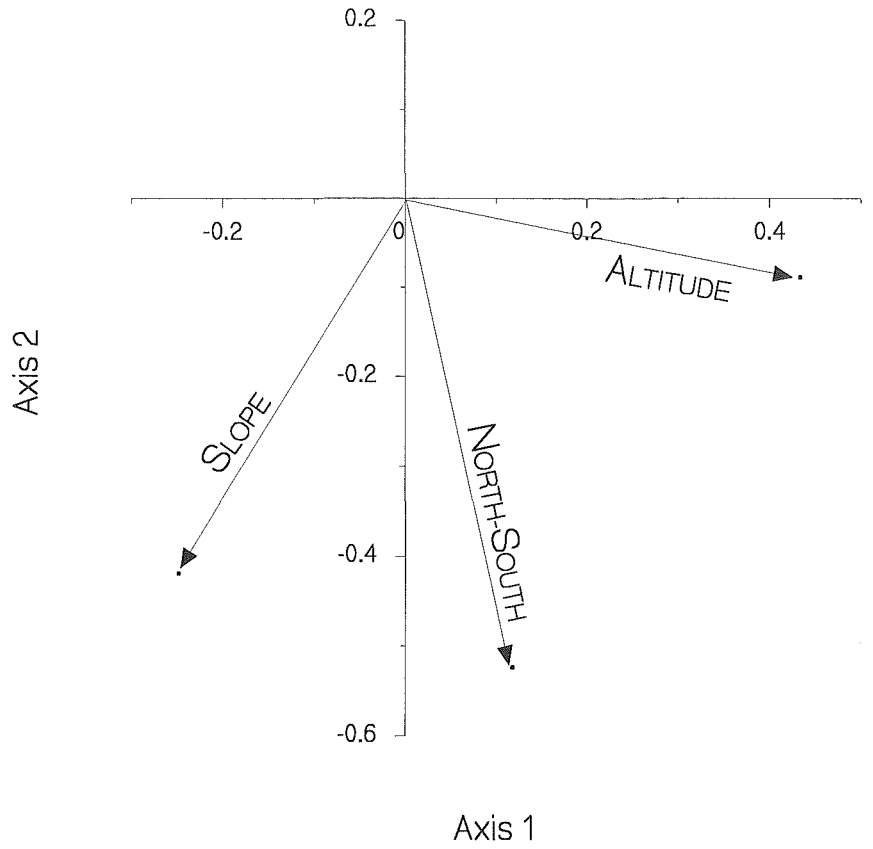


Figure 3.12 Diagram of Spearman rank correlations between significant environmental variables and position of plots on axes 1 and 2 of the cover ordination. Altitude is significantly correlated with axis 1 ($P<0.05$), in a positive direction. The cosine of aspect, *i.e.* north-south is significantly correlated with axis 2 ($P<0.01$), in a negative direction. Slope is also significantly correlated with axis 2 ($P<0.05$) in a negative direction.

The rank abundance plots (Fig. 3.13) differentiates the communities into two groups. Group one consists of the grassland and the subalpine communities. Both these communities are taxonomically poor in comparison to the other three communities. They also exhibit a broad pattern of dominance, suggesting that groups of species are able to dominate these two communities. They are also, arguably, the most physically disturbed communities. Group two consists of kanuka, mountain beech and scrub-grassland communities. All three communities are taxonomically more diverse than the group one communities, and also exhibit clear dominance by only one or at most three species. The kanuka community, while poorly sampled in terms of number of sites, clearly exhibits a high level of diversity (a similar high level of diversity was found in Isolated Hill Scenic Reserve).

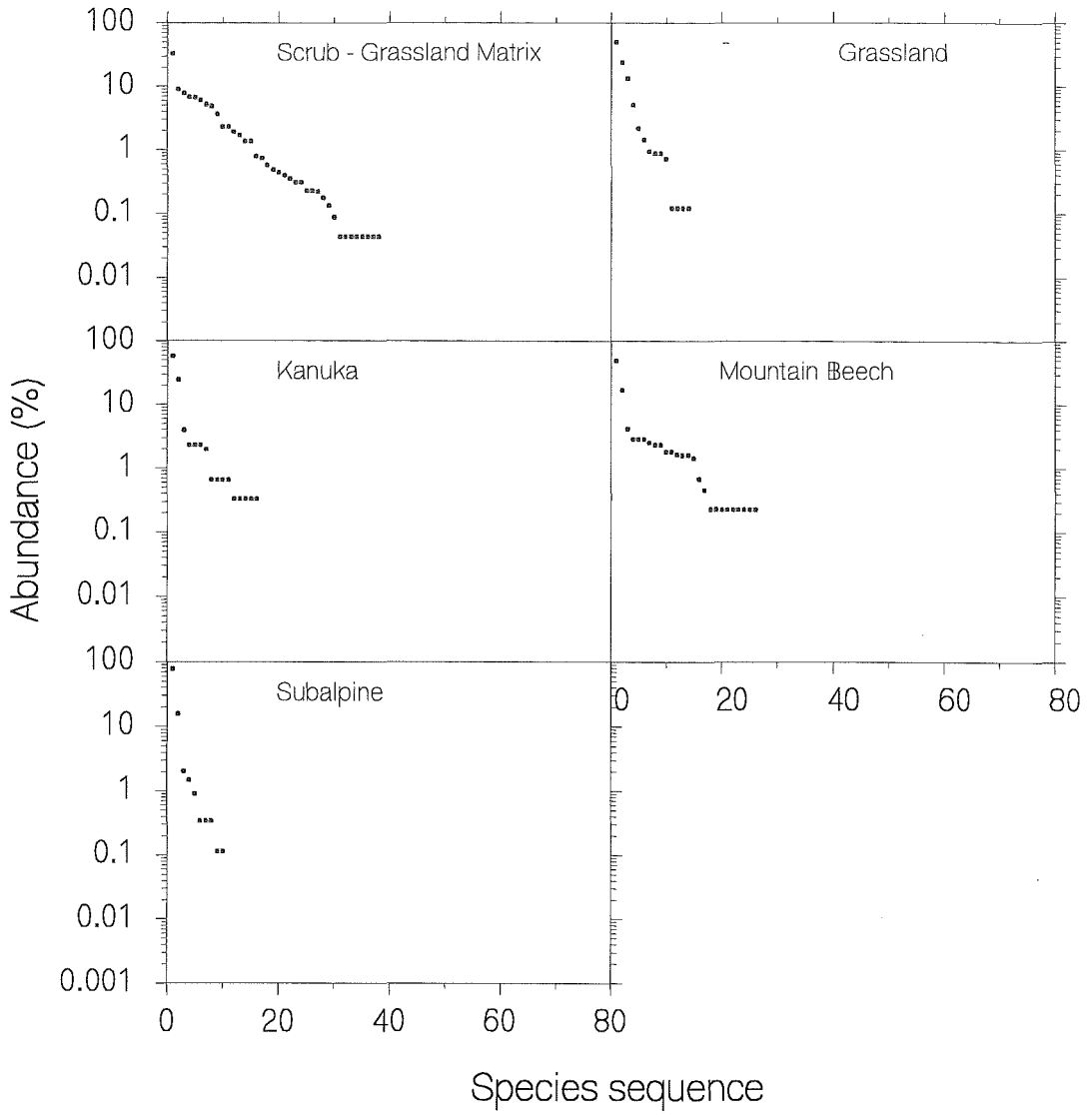


Figure 3.13 Species rank abundance plots for the five vegetation communities identified for Black Angel Creek. The graphs give a clear indication of comparative taxonomic richness and of the dominance of species within each of the communities.

Tier structure diversity (Fig. 3.14) shows marked differences between the different communities. Perhaps most striking is the presence of only one tier in the mountain beech community, indicative of the long history of alteration by domestic stock and grazing management. The grassland community also recorded only a single tier, a result that testifies to the effectiveness of fire in removing non-palatable species on pastoral leaseholds (an area of approximately 5 ha was burned in August 1996). Apart from the

grassland community, no clear divisions can be made between the communities because of tier structure and tier diversity.

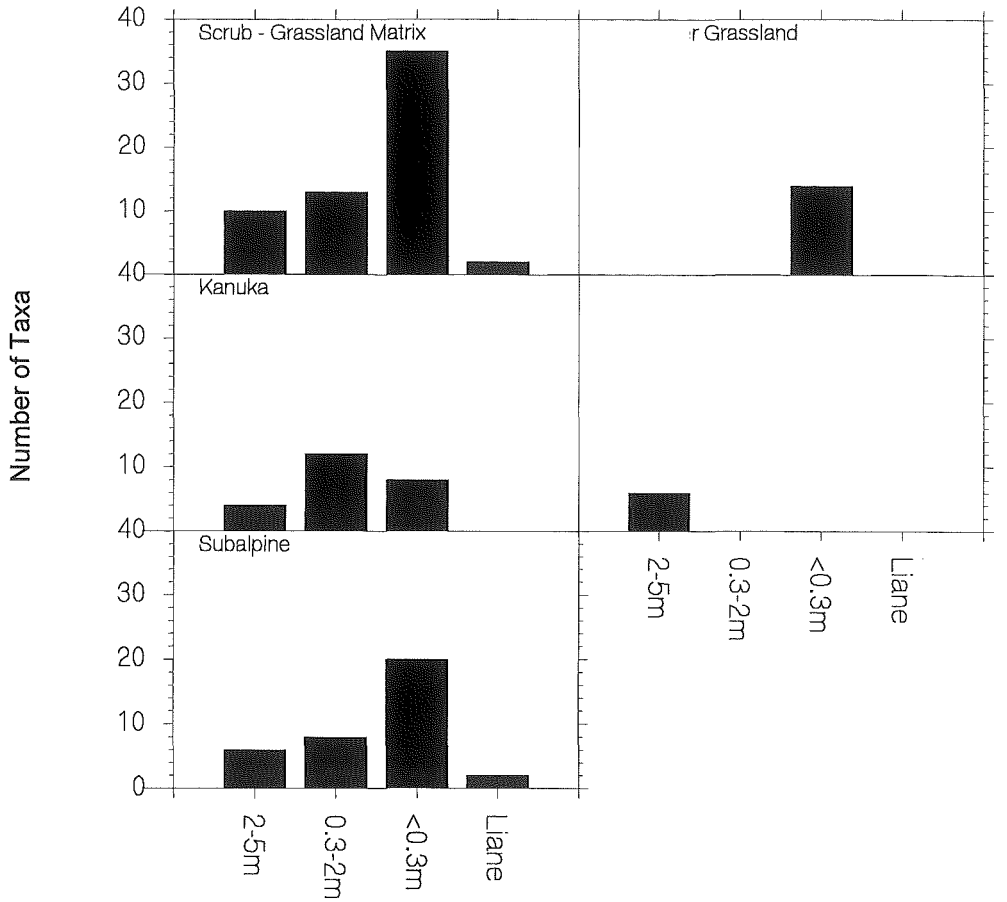


Figure 3.14 Taxonomic richness in individual tier classes for each of the five vegetation communities described for Black Angel Creek.

Table 3.13 records the community indices recorded for the five vegetation types in the Black Angel Creek area. From the two diversity indices the kanuka community is clearly (once again despite a low sample number) the most diverse community present in the study area. The subalpine community is again (see Isolated Hill Scenic Reserve vegetation communities) the least diverse of the communities present (Fig. 3.16 shows rank position for the different communities). In terms of a dominance index, the kanuka community falls in the middle range of the Berger-Parker indices recorded for the area. The subalpine community has the highest Berger-Parker index at a level of 0.78 (the dominant species is *Poa cita*). At the other end of the scale is grassland at 0.51, representing the joint dominance by a group of species of that vegetation community. The final index is the vegetative cover index, which ranges from 55 to a value of 157.

Table 3.13 Taxonomic richness, Margalef's index, Berger-Parker dominance index and cover index for the five identified vegetation communities in the Black Angel Creek study area. Figures are mean value ± 1 S.E.

Community	Taxonomic richness	Margalef's index	Berger-Parker index	Cover index
Scrub-Grassland Matrix	8.77 (± 0.73)	2.10 (± 0.26)	0.53 (± 0.07)	89 (± 17.57)
Grassland	9.33 (± 0.33)	1.88 (± 0.22)	0.51 (± 0.11)	108 (± 42.06)
Kanuka	16.00	2.97	0.56	157
Mountain Beech	11.50 (± 0.29)	2.67 (± 0.17)	0.67 (± 0.08)	55 (± 9.28)
Subalpine	5.25 (± 0.63)	0.95 (± 0.15)	0.78 (± 0.07)	90 (± 8.44)

Of particular interest in the Black Angel Creek area is that the mountain beech community has the lowest average cover index (55), a score which is indicative of the changes caused by grazing management. Figure 3.15 shows the rank position of each of the vegetation communities for the four community indices. The two diversity indices (taxonomic richness and Margalef's index ((A) and (B) respectively)) show similar positioning of the communities except in the case of grassland and the scrub-grassland communities.

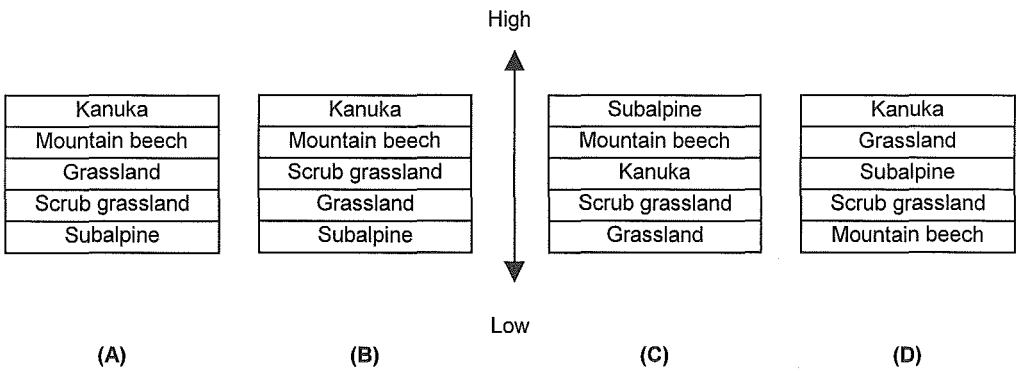


Figure 3.15 Graphical representation of the rank of communities for four different community indices. The four indices are (A) taxonomic richness, (B) Margalef's index, (C) Berger-Parker index, and (D) cover index. Community rank was decided by mean values for each of the indices.

3.4.2. The vegetation communities – 1. Scrub – Grassland matrix

This community was recorded at altitudes between 250 and 950 m (average altitude 559 m). The community was represented in a broad range of compass aspects, although sites tended (nine from thirteen) to have a northerly aspect. Slopes varied between 15° and 55°, with the average slope 31.8° ± 4.1° (1 S.E.). Physiographically, the majority of sites were faces, however, ridge, gully and terrace sites were also recorded. At all sites drainage was good.

For this community 38 different taxa were recorded (key species are listed in Table 3.14). Three different tiers had vegetation represented in them. In the tier 2-5 m, *Coprosma propinqua*, *Cordyline australis*, *Griselinia littoralis*, *Leptospermum scoparium*, *Kunzea ericoides*, *Melicytus ramiflorus*, *Pennantia corymbosa*, *Podocarpus hallii*, and *Sophora microphylla* were all present. In the browse tier 13 taxa were present, with *Coprosma propinqua* dominant. In the seedling tier, 35 taxa were present with the most dominant taxon *Anthoxanthum odoratum*. Other important taxa in this tier were *Chionochloa* sp., and *Pteridium esculentum*.

Table 3.14 Percentage cover and percentage occurrence of plant species in the Scrub – Grassland matrix community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=13).

Species	Mean percentage cover	Percentage frequency
Anthoxanthum odoratum	29.3	92.3
Chionochloa sp.	8.0	30.8
Coprosma propinqua	6.9	69.2
Linum catharticum	6.0	15.4
Podocarpus hallii	5.8	7.7
Kunzea ericoides	5.3	30.8
Discaria toumatou	4.5	38.5
Leptospermum scoparium	4.3	15.4
Cassinia leptophylla	3.2	46.2
Melicytus ramiflorus	2.0	30.8
Echium vulgare	2.0	53.8
Muehlenbeckia sp.	1.7	30.8
Dactylis glomerata	1.5	38.5
Pennantia corymbosa	1.2	7.7
Pteridium esculentum	1.2	7.7

3.4.3 The vegetation communities 2. – Grassland

The community has an altitudinal range of 650-750 m (average altitude 721 m). The grassland community is north-facing with variation between north-northwest and north-northeast. Slopes for the community vary between 30° and 40° (average slope 36.3°, ± 0.5° (1 S.E.)). Drainage at all sites was good.

The total number of recorded plant taxa for this community was 14 (key species listed in Table 3.15). Only the seedling tier was represented and this was dominated (71.6% of all vegetative cover) by two species *Dactylis glomerata* and *Achillea millefolium*. Also abundant is *Echium vulgare*.

Table 3.15 Percentage cover and percentage occurrence of plant species in the Burnt-over Grassland community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=3).

Species	Mean percentage cover	Percentage frequency
Dactylis glomerata	38.3	100.0
Achillea millefolium	33.3	66.7
Echium vulgare	18.5	100.0
Holcus lanatus	7.0	100.0
Cirsium vulgare	3.0	100.0
Agrostis tenuis	2.0	66.7
Taraxacum officinale	1.3	100.0
Verbascum thapsus	1.2	66.7
Wahlenbergia albomarginata	1.2	66.7
Anthoxanthum odoratum	1.0	33.3

3.4.4 The vegetation communities 3. – Kanuka

The kanuka community is poorly represented in this review of the vegetation types in Black Angel Creek, and hence results should be considered tentative. The site was recorded at 300 m and had an aspect of 300°. The slope of the site was 3°, and physiographically is best described as a terrace site. The drainage at the site was good. The number of taxa recorded for this vegetation type was 16 (for key taxa see Table 3.16). The site was dominated by *Kunzea ericoides* and *Pseudopanax arboreus*. These two species dominated the 2-5 m tier with only two other species present, *Coprosma robusta* and *Coriaria arborea.* The browse tier has 12 taxa present, with the common taxa being *Podocarpus totara*, *Pseudopanax crassifolium*, *Coprosma propinqua*, *Corokia cotoneaster*, and *Olearia paniculata.* The seedling tier is dominated by *O .paniculata* and *P. totara.* Other taxa present in this tier include *Echium vulgare*, *Dactylis glomerata*, *Griselinia littoralis*, and *Olearia nummularifolia.*

Table 3.16 Percentage cover and percentage occurrence of plant species in the Kanuka community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=1).

Species	Mean percentage cover	Percentage frequency
Kunzea ericoides	87.5	100.0
Pseudopanax arboreus	37.5	100.0
Podocarpus totara	6	100.0
Coprosma propinqua	3.5	100.0
Olearia paniculata	3.5	100.0
Pseudopanax crassifolium	3.5	100.0
Corokia cotoneaster	3	100.0
Coprosma robusta	1	100.0
Coriaria arborea	1	100.0
Griselinia littoralis	1	100.0
Olearia nummularifolia	1	100.0

3.4.5 The vegetation communities 4. – Mountain Beech

This community occurs in the altitudinal range 650 – 900 m. The community occurs on south facing sites that have slopes of between 20° and 40° (average slope 27.8°, ± 1.5° (1 S.E.)). All of the measured sites were located on faces, although gully sites were also observed by the author. The drainage at all sites was good.

The community had a total of 25 plant taxa recorded (for key species see Table 3.17). The vegetation is dominated by *Nothofagus solandri* and *Podocarpus hallii*, which dominate the 2 - 5 m tier. Other species present in this tier are *Carpodetus serratus*, *Griselinia littoralis*, *Melicytus ramiflorus*, and *Pittosporum eugenioides*. The browse tier is also dominated by *N. solandri*. The seedling tier has 20 plant taxa present, with *Holcus lanatus*, *Blechnum penna-marina*, and *Polystichum vestitum* dominating. The liane tier is also represented in this community with *Clematis* sp. and *Rubus* sp. present.

Table 3.17 Percentage cover and percentage occurrence of plant species in the Mountain Beech community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=4).

Species	Mean percentage cover	Percentage frequency
Nothofagus solandri	27.1	100.0
Podocarpus hallii	9.4	25.0
Holcus lanatus	2.3	75.0
Blechnum pennamarina	1.6	75.0
Polystichum vestitum	1.6	75.0
Rubus sp.	1.6	75.0
Carpodetus serratus	1.4	75.0
Griselinia littoralis	1.3	75.0
Urtica ferox	1.3	75.0
Coprosma propinqua	1	50.0

3.4.6 The vegetation communities 5. - Subalpine

The Subalpine community occurs at altitudes between 1000 and 1240 m (average altitude 1095 m). The aspects recorded were easterly in nature, with two sites having a north-east aspect, and two sites a south-east aspect. Slopes varied between 5° and 15°, with the average slope 8.8° ± 2.8° (1 S.E). Three of the sites were located on ridgelines, whilst the fourth was a face site. All sites had good drainage.

The total number of taxa described for the Subalpine community was 10 (key species in Table 3.18). Only the seedling tier was found in this community, and the tier was dominated by *Poa cita* and a *Celmisia* species. Low-growing shrub species were present in low numbers. The shrub species present were *Cassinia leptophylla*, *Coprosma propinqua*, *Discaria toumatou*, *Gaultheria* sp., and *Helichrysum bellidioides*. Also present were *Aciphylla* sp., *Blechnum penna-marina*, and *Dactylis glomerata.*

Table 3.18 Percentage cover and percentage occurrence of plant species in Subalpine community. Only species with a combined cover of > 1% are listed. Percentage occurrence is the percentage of quadrats that the species was recorded in (n=4).

Species	Mean percentage cover	Percentage frequency
Poa cita	68.8	100.0
Celmisia sp.	13.9	75.0
Cassinia leptophylla	1.8	50.0
Discaria toumatou	1.3	75.0

3.5 Discussion

3.5.1 Communities identified at Isolated Hill Scenic Reserve and Black Angel Creek

Clearly arbitrary decisions are needed if vegetation types are to be defined. This is in keeping with Burrows (1990) assertion that communities are an "arbitrary subdivision of a continually varying pattern of species composition." By combining conglomerative and agglomerative clustering methods and ordination methods a relatively objective description of the communities can be made. However, such methods are themselves open to subjectivity. For example polythetic agglomerative clustering is sensitive to group size weighting in the group average linkage method and further requires subjective decisions about cut-off levels. In a wider context arbitrariness can be observed in the choice of cover data in the detrended correspondence analysis, as opposed to presence/absence data. That choice alludes to the strong overlap in species between communities, hence the need for a quantitative factor if communities are to be separated.

Eleven communities are recognised for Isolated Hill Scenic Reserve and five for Black Angel Creek (Table 3.19). A clear division appears between communities which experience extreme conditions (for example the bluffs and screes community at Isolated Hill Scenic Reserve, and the subalpine communities in both study areas) and

Table 3.19 Communities identified at Isolated Hill Scenic Reserve and Black Angel Creek study areas. Community name and key components (two highest cover species).

Number	Community Name	Key Vegetative Components
Isolated Hill		
1	Red Beech	*Nothofagus fusca, Pseudowintera colorata*
2	Mountain Beech	*Nothofagus solandri, Melicytus ramiflorus*
3	Hall's Totara	*Podocarpus hallii, Myrsine divaricata*
4	Kanuka	*Kunzea ericoides, Helichrysum aggregatum*
5	Broadleaf	*Griselinia littoralis, Melicytus ramiflorus*
6	Matai	*Prumnopitys taxifolia, Olearia paniculata*
7	Mahoe-Titoki	*Prumnopitys taxifolia, Melicytus ramiflorus*
8	Bluffs and Screes	*Gentiana astonii, Dodonaea viscosa*
9	Subalpine	*Poa cita, Chionochloa* sp.
10	Grass-Scrubland	*Agrostis capillaris, Holcus lanatus*
11	Improved Grassland	*Dactylis glomerata, Discaria toumatou*
Black Angel Creek		
1	Scrub-Grassland matrix	*Anthoxanthum odoratum, Poa cita*
2	Grassland	*Dactylis glomerata, Achillea millefolium*
3	Kanuka	*Kunzea ericoides, Pseudopanax arboreus*
4	Mountain Beech	*Nothofagus solandri, Podocarpus hallii*
5	Subalpine	*Celmisia* sp. *Chionochloa* sp.

communities that are in some manner protected from extreme abiotic factors, whether by structural cover, or by the benefit of low altitude. The subalpine communities in both areas have the lowest taxonomic richness, and the lowest Margalef's index (Tables 3.1 and 3.13). Similarly, at Isolated Hill Scenic Reserve the bluffs and screes community is the next lowest ranked for both indices.

At the opposite end of the scale are communities such as matai, mountain beech, and red beech at Isolated Hill Scenic Reserve, and kanuka and mountain beech at Black Angel Creek. At Isolated Hill, the matai and beech communities are typically found at lower altitudes. Matai and mountain beech communities are found on medium slopes, whilst the red beech community is found on small to medium slopes. At Black Angel Creek, the kanuka community is restricted to the lower slopes of the valley, while the mountain beech community occurs at mid-altitudes.

Comparison of the tier diversity diagrams (Figures 3.10 and 3.17) between the two areas alludes to the impacts that human management has on natural or even semi-natural systems. Black Angel Creek which has been subject to grazing management since the early 1900's (and to possible burning whilst Maori were hunting moa prior to this)

exhibits poor tier diversity in all of the identified communities. An extreme example of this is the grassland community (actively managed for pastoral values) that has only one tier present. Conversely, Isolated Hill Scenic Reserve has suffered only minor intrusions by grazing livestock, apart from one attempt to graze stock on the side of Isolated Hill in the late 1800s which was an abject failure (Department of Conservation Internal File No. 13/25 Vol. 1). Of the nine indigenous communities recorded within the reserve only the subalpine community lacks a diverse tier structure.

3.5.2 Comparison between current and past vegetation studies at Isolated Hill Scenic Reserve

While previous botanical studies have occurred in the area of interest, these studies have not been quantitative, except for the studies of Hayward (1985), and Cochrane (1994). Of the previous descriptive botanical surveys (Williams and Druce, 1979; Williams, 1982; Breese *et al.*, 1986; Druce and Williams, 1989; O'Brien, 1993), the study by Druce and Williams (1989) is the most extensive. It is the definitive study in terms of taxonomic description of vegetation within the study area. Their paper lists eight forest, treeland, and shrub communities, six scrub and shrubland communities, one sedge-grassland community, and one openland community (Fig. 3.16). A number of the communities described by Druce and Williams have been amalgamated in this study. Elements of the *Myoporum laetum* and *Dodonaea viscosa* community described by Druce and Williams are included in three of the communities in this study (broadleaf, matai, mahoe –titoki communities). The *Dacrydium cupressinum* community described by Druce and Williams is restricted to the headwaters of the Kekerengu River, an area which was not visited during this study (and an area that has very low feral gaot numbers (M. Brennan, pers. comm.)). Druce and Williams' *Aristotelia serrata* and *Coriaria arborea* community was placed into the broadleaf and mahoe-titoki communities. The *Phyllocaldus alpinus/Podocarpus hallii* was classified as the Hall's totara community. Finally, the *Carex – Poa cita* community is restricted to the wetland area near the Zoo hut (on the inland side of Isolated Hill Scenic Reserve), an area that was not quantitatively measured during this study.

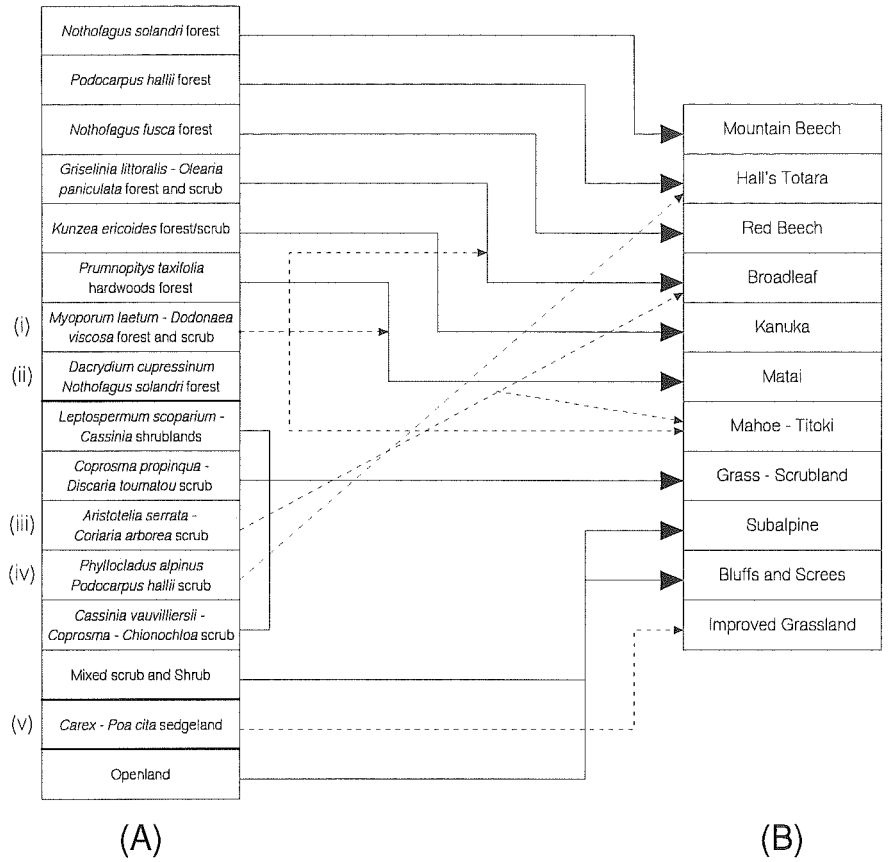


Figure 3.16 Diagrammatic representation of the vegetation communities described by (A) Druce and Williams (1989) and the equivalent vegetation communities (B) of this study. Solid lines represent direct relationship, while broken represent communities in which elements are distributed into different communities in this study. Notes are (i) elements of the *Myoporum laetum* and *Dodonaea viscosa* community described by Druce and Williams are included in three of the communities in this study. (ii) The *Dacrydium cupressinum* community described by Druce and Williams is restricted to the headwaters of the Kekerengu River, an area not visited during this study. (iii) and (iv) elements of both of these communities are included in different communities as indicated. (v) The *Carex – Poa cita* community is restricted to the wetland area near the Zoo hut. The wetland was not quantitatively measured during this study.

Another earlier study by Williams (1982) provides a list of 12 vegetation communities recognised within Isolated Hill Scenic Reserve itself (Table 3.20). Again some changes occur in the classification of vegetation communities in that study and this study. The akeake/koromiko/manuka community is split into the broadleaf, mahoe-titoki, and bluffs and screes communities. Akeake (*Dodonaea viscosa*) is a common component of the broadleaf community but is also found intergrading with the bluffs and screes community (as is manuka (*Leptospermum scoparium*)). The silver tussock grassland is incorporated into the grass/scrubland community along with Tauhinu/*Coprosma* scrub. The improved

grassland community is fundamentally a new community, primarily because previous studies have concentrated upon indigenous or semi-indigenous vegetation communities alone. However, it is inappropriate to draw that division, especially when dealing with a pest such as feral goats which simply do not recognise cadastral boundaries. It also reflects the change in paradigm from conservation only on conservation estate to conservation on non-conservation estate as represented by the draft New Zealand biodiversity strategy (Anon, 1998). In the case of both studies, this thesis acts to pool vegetation communities as opposed to being divisive. Differences may also be explained in the different approaches to assessing the communities present in the area.

Table 3.20 Vegetation communities from Williams (1982) compared to vegetation communities from current study.

Vegetation Communities from Williams (1982)	**Vegetation Communities from current study**
Matai/broadleaf/mahoe forest	Matai
Red Beech forest	Red Beech
Mountain Beech forest	Mountain Beech
Hall's Totara forest	Halls Totara
Hall's totara/mountain toatoa	
Broadleaf/ake ake forest	Broadleaf
Kanuka forest	Kanuka
Ake ake/koromiko/manuka scrub	Mahoe – Titoki
Scarps	Bluffs and Screes
Tauhinu/*Coprosma* scrub	Scrub – Grassland
Silver tussock grassland	Subalpine
Snowgrass/*Coprosma* shrubland	Improved Grassland

The two available quantitative studies (Hayward, 1985; Cochrane, 1994) are limited to Isolated Hill Scenic Reserve. Both studies used subjectively placed New Zealand Forest Service vegetation quadrats that Hayward had erected, and it was that initial decision to subjectively place the vegetation quadrats that leads to the inherently limited conclusions that can be drawn from the studies. Stand parameters from those two studies and this study (Table 3.21) show similarities only in the most dominant species of each vegetation type. Less dominant species often exhibit a higher percentage in the study of Hayward (1985) and Cochrane (1994), than in this current study. This is primarily due to the different methods used to express proportional representation (Hayward's study is expressed as percentage of total basal area whereas the current study is percentage of total

cover), although some differences will be because of the more substantial data set collected for this study.

Hayward (1985) specifically noted the distinctive nature of the flora of the Isolated Hill Scenic Reserve, as did Williams (1982) and Druce and Williams (1989). Hayward suggests that much of this uniqueness is due to the complex geology to be found within the area and notes in particular the vegetative differences between calcareous areas and acidic rock type areas. Calcicoles are abundant on the calcareous substrate, while beech communities are restricted to the acidic rock types. Hayward comments that the understorey of the beech areas has been extensively modified by mammalian herbivores, although they still retained ample forage species in the form of *Coprosma* shrubs. Hayward noted that this was in direct contrast to adjoining calcareous areas. Comparison of commonly occurring *Coprosma* species cover from this study (Table 3.22) shows that Hayward's assertion is incorrect. *Coprosma crassifolia* occurs most abundantly in the kanuka and matai communities, both of which occur on calcareous substrate. For the mountain beech vegetation community, the only *Coprosma* species with high percentage cover are *C. linariifolia*, and *C. rhamnoides* with 4.80 and 12.80 percent respectively. Even in the case of these two species the kanuka community has higher cover at 6.50 and 15.20 percent respectively. Hence, it is not possible to suggest that beech communities have a high potential browse resource in the form of *Coprosma* species.

The study by Cochrane (1994) was based upon the design of Hayward (1985). Stand parameters from the Cochrane study are also presented in Table 3.21. Differences between the Cochrane (1994) study and Hayward (1985) study appear in the addition in the Cochrane study of an additional vegetation community – Red Beech. This arises from classification differences between the two studies. Similarly to the Hayward study, Cochrane (1994) stand parameters are different from the percentage cover figures found in this study. However, the diameter at breast height (DBH) detrended correspondence analysis of Cochrane (1994) found that altitude and north-south aspect were significantly correlated with the position of vegetation quadrats on axes one and two. The results of a similar analysis (albeit on a more complete data set) in this study also found that altitude and north-south aspect were significantly correlated with the position of vegetation

quadrats on axes one and two. Further, two other environmental variables were found to have significant correlations – slope and drainage. The significant result for drainage is not helpful, as very few quadrats were assessed as having anything other than good drainage.

Table 3.21 Species basal diameter percentages and percentage at Isolated Hill Scenic Reserve for 1985, 1993, and the current study. Five vegetation communities are compared. Basal diameter figures are pooled figures for diameter at breast height, sapling, and seedling data. Adapted from Hayward (1985), and Cochrane (1994).

Vegetation type and species	Percentage of total basal area (Hayward, 1985)	Percentage of total basal area (Cochrane, 1994)	Percentage of Cover (current study)
Broadleaf			
Griselinia littoralis	18.70	26.95	20.60
Carpodetus serratus	19.99	24.36	0.50
Pittosporum eugenioides	7.61	9.71	
Melicytus ramiflorus	17.35	7.84	18.00
Aristotelia serrata		6.89	0.19
Kunzea ericoides	2.67	6.77	16.40
Myrsine australis	4.49	3.84	4.30
Coprosma linariifolia	3.06	3.35	0.19
Sophora microphylla		2.57	0.19
Matai			
Prumnopitys taxifolia	46.29	40.56	24.70
Melicytus ramiflorus	19.71	21.68	7.60
Griselinia littoralis	12.98	13.17	8.70
Myrsine australis	4.05	3.95	2.50
Podocarpus hallii		3.42	0.09
Kunzea ericoides	3.36	3.34	9.00
Carpodetus serratus	2.68	2.49	2.12
Nothofagus solandri		1.99	1.40
Kanuka			
Kunzea ericoides	66.83	65.83	55.5
Pittosporum eugenioides		7.01	1.40
Griselinia littoralis		6.31	7.40
Carpodetus serratus	21.41	5.23	0.50
Coprosma linariifolia		5.10	6.50
Pseudopanax crassifolium	3.29	3.40	0.59
Myrsine australis		3.13	0.04
Melicytus ramiflorus		2.89	0.25
Red Beech			
Nothofagus fusca		48.19	43.50
Prumnopitys taxifolia		12.75	0.33
Carpodetus serratus		11.85	5.00
Griselinia littoralis		10.73	1.14
Myrsine australis		4.78	2.70
Pittosporum eugenioides		4.24	0.04
Melicytus ramiflorus		2.83	

Table 3.21 Cntd Species basal diameter percentages and percentage at Isolated Hill Scenic Reserve for 1985, 1993, and the current study. Five vegetation communities are compared. Basal diameter figures are pooled figures for diameter at breast height, sapling, and seedling data. Adapted from Hayward (1985), and Cochrane (1994).

Vegetation type and species	Percentage of total basal area (Hayward, 1985)	Percentage of total basal area (Cochrane, 1994)	Percentage of Cover (current study)
Hall's Totara			
Podocarpus hallii	89.59	80.52	60.5
Griselinia littoralis	8.55	7.62	0.2
Pittosporum eugenioides		5.47	0.2
Carpodetus serratus	0.84	0.57	0.8
Myrsine divaricata	0.51	0.34	2.4
Pseudopanax crassifolium	0.28	0.27	0.3
Myrsine australis	0.13	0.12	0.1
Coprosma rhamnoides		4.44	2.0
Coprosma linariifolia	0.09	0.11	0.4
Helichrysum aggregatum		0.19	
Urtica ferox		0.75	0.8

Table 3.22 Percentage cover of *Coprosma* species in the different vegetation communities identified at Isolated Hill Scenic Reserve and Black Angel Creek. Species codes are CC *Coprosma crassifolia*, CL *Coprosma linariifolia*, CP *Coprosma propinqua*, CRH *Coprosma rhamnoides*, CRO *Coprosma robusta*.

Vegetation Community	*Coprosma* Species percentage cover				
Isolated Hill Scenic Reserve	***CC***	***CL***	***CP***	***CRH***	***CRO***
Red Beech		2.3	0.15	4.70	
Mountain Beech	0.25	4.80	0.13	12.80	0.05
Hall's Totara		0.40	0.70	2.00	
Kanuka	7.00	6.50	1.40	15.20	
Broadleaf		0.19	4.40	0.13	
Matai	3.50	5.40	0.70	2.30	0.34
Mahoe-Titoki		0.32	0.23	0.09	
Bluffs and Screes		0.12	0.45	0.17	
Subalpine			1.50		
Grass-Scrubland			0.08		
Improved Grassland			0.60	0.02	
Black Angel Creek					
Scrub-Grassland matrix			6.90		
Grassland			0.17		
Kanuka			3.50		1.00
Mountain Beech		0.38	1.00		
Subalpine			0.30		

A further analysis performed by Cochrane (1994) was that of palatability versus quadrat position on axes one and two of a detrended correspondence analysis of sapling species. Palatability was found to be significantly correlated with axis one position (and was significantly correlated with whether vegetation quadrats were exclosures or not).

Cochrane suggested that palatable species were restricted to certain vegetation types and in particular to the three exclosures within Isolated Hill Scenic Reserve. However, this study has found that saplings of palatable species (in particular *Griselinia littoralis* and *Melicytus ramiflorus*) whilst definitely of lower abundance than other species, are not restricted to only a few vegetation communities (Table 3.23).

The vegetation study by Cochrane (1994) finished by outlining a vegetation change model for the vegetation communities at Isolated Hill Scenic Reserve (Table 3.24). The model differentiated between vegetation communities susceptible to physiognomic changes caused by feral goat browsing and those that were not (type 1 and 2). Cochrane asserted that both vegetation categories were at stage three of his model. Stage three is such that palatable species are removed from the type two vegetation types (vegetation communities less affected physiognomically by feral goats), and type one vegetation types face virtual replacement of palatable species with unpalatable species. Clearly from the work presented here highly palatable species (for example *Melicytus ramiflorus*) are surviving in the type two vegetation communities (Table 3.23) (except in the case of the Halls totara community).

Table 3.23 Frequency of occurrence of two highly preferred food species (*Griselinia littoralis* and *Melicytus ramiflorus*) for forest communities at Isolated Hill Scenic Reserve. Number of vegetation plots surveyed in each vegetation type is recorded after the community name.

Community	Seedling tier (0-0.3m) frequency	Sapling tier (0.3-2m) frequency	Understorey tier (2-5m) frequency
Griselinia littoralis			
Mountain beech (12)	41.7	0	25
Red beech (12)	58.3	16.7	58.3
Hall's totara (5)	0	0	40
Kanuka (14)	64.3	14.3	35.7
Broadleaf (8)	50	0	87.5
Matai (11)	100	9.1	36.4
Mahoe-titoki (11)	27.3	0	45.5
Melicytus ramiflorus			
Mountain beech (12)	50	58.3	100
Red beech (12)	0	0	0
Hall's totara (5)	0	0	0
Kanuka (14)	7.1	7.1	0
Broadleaf (8)	25	12.5	62.5
Matai (11)	63.6	27.3	72.7
Mahoe-titoki (11)	9.1	0	100

This is at odds with Cochrane (1994) (stage 2 in which palatable species are removed) and suggests that these vegetation types may in essence act as refugia for at least some palatable species (for example the growth of *Griselinia littoralis* in the 0.3 – 2m tier in the red beech and kanuka community, and the growth of *Melicytus ramiflorus* in the same tier in the mountain beech community (Table 3.23)). This however, implies a differential use of vegetation communities by feral goats, an assertion that this thesis hopes to test. This study supports Cochrane (1994) with regards the dominance of unpalatable species (for example *Coprosma rhamnoides*) in type one vegetation types. Once again these findings can be used to infer differential vegetation community utilisation by feral goats. Hence, it is clear that the spatial and temporal heterogeneity of the vegetation must be accounted for when considering the relationship between vegetation and mammalian herbivores. This brings the focus of studies onto how animals affect successional vegetation patterns rather than merely what they eat.

Table 3.24 Vegetation change model suggested by Cochrane (1994) for two classes of vegetation types present in Isolated Hill Scenic Reserve. Bold text at Stage 3 is suggested as the stage of change current in the reserve at the end of the study in 1993.

Vegetation Change Model for Isolated Hill Scenic Reserve		
Stage	**Feral goat induced changes in palatable vegetation types (Matai, and Broadleaf)**	**Feral goat induced changes in unpalatable vegetation types (Kanuka, Hall's Totara, and Red Beech)**
	Vegetation Type 1	**Vegetation Type 2**
1	Arrival of feral goats, browsing of most species and identification of palatable species. Increased erosion through animal presence.	Arrival of feral goats, browsing of most species and identification of palatable species. Increased erosion through animal presence.
2	Heavy browsing of palatable species. Reduction of litter volume. Increase in unpalatable shrub species.	Use of vegetation types for movement to other areas. Removal of palatable understory species.
3	**Virtual replacement of understory by unpalatable species, increased occurrence of Uncinia spp., and invasion of exotic herbs and grasses**	**Continued regeneration of canopy species, some opening up of the understory.**
4	Disturbance events and natural mortality remove canopy species. Subsequent canopy species are those that are unpalatable. Fragmentation of forest communities.	Not applicable.

3.6 Conclusion

Vegetation communities can be recognised for Isolated Hill Scenic Reserve and Black Angel Creek. However these communities act only as reference points within a

continuously varying mosaic of vegetation. This chapter has investigated the different communities in the two study areas and characterised them in terms of key species, diversity, and physical relationships. Specific findings are:

1. eleven communities have been defined at Isolated Hill Scenic Reserve, and five communities at Black Angel Creek. At Isolated Hill Scenic Reserve the communities are bluffs and screes, broadleaf, grass/scrubland, Hall's totara, improved grassland, kanuka, mahoe-titoki, matai, mountain beech, red beech and subalpine grassland. At Black Angel Creek the five communities are grassland, kanuka, mountain beech, scrub/grassland, and subalpine.
2. key plant species (>1% cover abundance) have been identified for all of the communities at Isolated Hill Scenic Reserve and Black Angel Creek.
3. species diversity indices and physical characters for the different communities have been identified for use in habitat selection modelling in Chapter 4.
4. A vegetation map of Isolated Hill Scenic Reserve has been developed from aerial photographs and ground surveys. The map shows the extent and coverage of vegetation communities within Isolated Hill Scenic Reserve and its immediate surrounds.

Clear unambiguous vegetation communities do exist in both study areas. To arrive at those communities a mixture of precise species descriptions and community parameters is needed. Equally clearly, randomly located as opposed to subjectively placed vegetation quadrats are required to give that objective description of the vegetation, and it is also clear that a quantitative as opposed to qualitative approach to vegetation description is more appropriate in this thesis. That accurate description of vegetation feeds directly into the habitat utilisation analysis of chapter 4.

Chapter 4 – Habitat selection by feral goats at Isolated Hill Scenic Reserve and Black Angel Creek

4.0 Introduction

Feral goats have been present in the Isolated Hill/Kekerengu area since before 1920 (Cochrane, 1994). Feral goats are a concern for both conservationists and pastoralists in the area (D. Buick *pers. comm.*) as they impact upon both conservation and pastoral values.

Earlier studies of feral goats in New Zealand (Riney and Caughley, 1959; Atkinson, 1964; Clark, 1974; Williamson, 1975; Parkes, 1984; Hayward, 1985; Mitchell *et al.*, 1987; Sherley, 1988; Hawes, 1989; Rudge, 1990; Brennan, 1992; Brennan *et al.*, 1993; Parkes, 1993; Cochrane, 1994; Stronge *et al.*, 1997) have primarily focussed upon impacts upon native vegetation and diet. None of the studies have investigated habitat selection for long periods of time, nor have any studies characterised changes in habitat selection subsequent to a control operation. This is an important area of research as knowledge of the behaviour of feral goats subsequent to control programmes would greatly assist in post-operational monitoring and subsequent control, by allowing monitoring of favoured habitats to detect residual feral goat mobs. Knowledge of habitat selection is of considerable importance if threats to at risk flora and fauna are to be accurately identified, and management programmes improved (see Chapter 5).

This chapter aims to describe habitat selection and use by feral goats at Isolated Hill Scenic Reserve. Specifically the chapter aims are:

1. to describe habitat selection at Isolated Hill Scenic Reserve and Black Angel Creek using direct observation and faecal pellet group densities;
2. to test for treatment (pre and post control) and seasonal differences in habitat selection;
3. to produce models of habitat selection using site variables;
4. to investigate diet as an explanatory variable for habitat selection.

4.1 Methods

4.1.1 Experimental design

The experimental design of the study at Isolated Hill Scenic Reserve was a before-after/control-impact (BACI) type design. Isolated Hill Scenic Reserve was the treatment area with the Department of Conservation providing a month long (November 1996) intensive hunting programme using professional hunters with dogs. A non-treatment area, Black Angel Creek, was located 2.5 km north of Isolated Hill Scenic Reserve. Black Angel Creek forms a part of Blue Mountains Station, a privately owned station that primarily farms sheep, and is isolated from Isolated Hill Scenic Reserve by the Waima River. Department of Conservation hunters did not operate in the Black Angel Creek area during the course of the study.

Two automated climate stations were established in the study area (one at Isolated Hill, and one at Black Angel Creek) during early 1996 to ensure that climatic conditions were similar at both sites. Data from the climate stations is presented in Appendix III. Initially it was hoped that rainfall and temperature at Isolated Hill Scenic Reserve and Black Angel Creek could be predicted from automated climate stations at Blenheim, Grassmere, and Kaikoura. The data would then be used as an explanatory variable for habitat selection. However prediction was not possible, and climate variables have not been included in the thesis.

Climate data were also recorded to monitor climatic trends at both study sites. This was for the purpose of ensuring that both sites received similar weather patterns, hence that Black Angel Creek could be treated as a non-treatment site for comparison with Isolated Hill Scenic Reserve.

4.1.2 Direct observation of feral goats

4.1.2.1 Field techniques

Feral goats were observed along a series of nine different transect lines in Isolated Hill Scenic Reserve and along one transect line in Black Angel Creek. Only one transect was used in Black Angel Creek as the area was substantially smaller than Isolated Hill Scenic Reserve and could be observed from a vehicle track located along a ridgeline. Transect lines in Isolated Hill Scenic Reserve were walked on 32 days during the pre-

control treatment (circa 320 observation hours) and 11 days during the post-control treatment (circa 110 observation hours). The transect line at Black Angel Creek was walked for 10 days (circa 100 observation hours) during the pre-control treatment period, and 7 days (circa 70 observation hours) during the post-control treatment period. Transects were only counted once per day, and goats were recorded as mobs and individuals. Goats were defined as a mob when individuals were observed feeding within 50 m of each other. Mobs were used as an independent unit of observation rather than individuals as social structure clearly determined where sub-dominant animals fed.

4.1.2.2 Analysis

Feral goat mob density was calculated for each vegetation type. Densities were calculated by dividing the number of feral goat mobs observed by the observable area of the vegetation community they were in. The observable areas for each vegetation type were calculated by placing a black and white square (20 cm × 20 cm) at eye-level in a shrub or tree and then moving away from it until it was difficult to see. The mean maximum distance that it could be observed at in each vegetation type was calculated, from ten distances measured in each vegetation community for each treatment period (Table 4.1). This was done to ensure that treatment did not affect observation distance within vegetation types. This was analysed using two-way analysis of variance (Table 4.2), and showed that while there were statistically significant differences between vegetation types, there were none between treatment periods.

Densities were pooled for treatment periods and seasonal periods for analysis. Transect lines in Isolated Hill Scenic Reserve each had different areas of vegetation communities along them. Vegetation areas were pooled for each day and also pooled for treatment periods. Vegetation communities contributed differently to total pre and post-control observation hours as the number of transects observed pre and post-control differed (Table 4.3), and hence the percentage contribution differed. Two-way analysis of variance was used to test for significant differences in feral goat habitat selection for treatments (pre and post-control) at Isolated Hill Scenic Reserve and Black Angel Creek, and for season at Isolated Hill Scenic Reserve. Habitat selection was not analysed seasonally at Black Angel Creek for two reasons:

1) access was constrained during spring months as farm blocks within Black Angel Creek and beside it were used for lambing;

2) replication of observation was not sufficient for all seasons (in particular winter, when access was limited due to rain and snow-fall).

Table 4.1 Mean maximum observable distance (metres) (± 1 S.E.) by vegetation community pre and post-control at Isolated Hill Scenic Reserve.

Vegetation communities	Pre-treatment	Post-treatment
Improved grassland	234.0 ± 46.7	241.5 ± 45.7
Subalpine	228.4 ± 37.6	204.6 ± 36.3
Grass/scrubland	157.1 ± 20.0	165.0 ± 23.2
Bluffs and Screes	123.4 ± 19.7	94.2 ± 19.3
Hall's totara	32.5 ± 3.4	33.9 ± 4.2
Broadleaf	28.3 ± 3.5	26.7 ± 3.5
Mahoe-Titoki	21.0 ± 2.3	23.9 ± 3.8
Red Beech	20.9 ± 2.3	19.1 ± 2.9
Matai	20.7 ± 1.7	20.7 ± 2.2
Mountain Beech	17.3 ± 1.9	15.5 ± 1.9
Kanuka	15.4 ± 0.8	15.3 ± 0.9

Table 4.2 Two way analysis of variance of treatment and visibility distance at Isolated Hill Scenic Reserve for pre and post-control treatments.

Source of Variation	SS	df	MS	F	P-value
Treatment	677.25455	1	677.25455	0.1693312	0.6811519
Vegetation	1490308.2	10	149030.82	37.261573	2.549E-40
Interaction	7108.5455	10	710.85455	0.1777321	0.9976283
Within	791917.8	198	3999.5848		
Total	2290011.8	219			

Table 4.3 Vegetation types sampled at Isolated Hill Scenic Reserve and Black Angel Creek pre and post-control as a percentage of total observation hours. At Black Angel Creek observation time was divided equally between communities, and all communities were sampled on each visit..

Vegetation communities	Percentage of total observation hours	
	Pre-control	Post-control
Isolated Hill Scenic Reserve		
Broadleaf	19.2	23.3
Mahoe-titoki	16.4	11.6
Mountain beech	12.3	4.7
Red beech	12.3	4.7
Bluffs and screes	8.9	18.6
Grass scrubland	8.9	11.6
Kanuka	8.2	9.3
Improved grassland	4.8	2.3
Hall's totara	3.4	4.7
Matai	2.7	7.0
Subalpine	2.7	2.3
Black Angel Creek		
Kanuka	20.0	20.0
Mountain beech	20.0	20.0
Grassland	20.0	20.0
Scrub – grassland	20.0	20.0
Subalpine	20.0	20.0

Two post-hoc tests were used to determine where significant differences lay, Tukey's HSD test and Duncan's multiple range test.

4.1.3 Faecal pellet group densities of feral goats

4.1.3.1 Field techniques

Faecal counts utilised the method of Baddeley (1985). Transect lines were utilised along which 5 m × 5 m quadrats were placed approximately every 50 metres. Transect start points were located at random starting points along river and stream. Transect direction normally followed topographical features (for example ridge or gully lines) except where terrain physically limited movement. Thirty transect lines were measured in total (10 in the Isolation catchment, 10 in the Waima catchment, and 10 in the Brian Boru catchment). Faeces were counted as pellet groups, which were defined as intact if six or more pellets were defecated in a discrete group and were recognisable without disturbing surrounding leaf litter and vegetation. Groups were counted if the mid-point of a group was within the bounded plot (Baddeley, 1985). Faeces were aged into three categories (fresh, medium, and old) based on colour and moisture. Fresh was defined as dark green or black in colour and moist to the touch or within the pellets; medium was defined as mid brown and not moist; and old was defined as light brown to white, not moist and plant fibres exposed and obvious. Five fresh faecal pellet groups were monitored in the Waima catchment to determine age subsequent to defecation at which pellets would be classified as medium rather than fresh. Groups were marked after defecation and revisited on subsequent visits. Classification change occurred at 20, 20, 22, 30, and 35 days old respectively, thus a mean of 25.4 days ± 3.0 (1 S.E.). All pellet data presented within the thesis is for fresh pellet groups only, as this allows for different temporal periods to be assigned to pellet groups.

4.1.3.2 Analysis

An initial pilot study of 40 faecal plots was recorded during 1995. Plots were distributed across several vegetation types (Table 4.4). Of the 40 plots, 27 had fresh pellet groups present on them, with an overall average density of 2.23 ± 0.50 (1 S.E.) fresh pellet groups per plot.

Table 4.4 Sampled vegetation communities in the 40 plot pilot study of fresh faecal pellet groups, Isolated Hill Scenic Reserve. All faecal pellet observations were restricted to fresh pellets only.

Vegetation community	Number of plots
Broadleaf	10
Mahoe-titoki	9
Improved grassland	6
Grass scrubland	5
Matai	3
Mountain beech	3
Subalpine	3
Bluffs and screes	1

Precision figures were calculated from the pilot study results for both presence/absence (Table 4.5) and pellet group numbers (Table 4.6), using formulae given by Neff (1968), and Baddeley (1985). Two hundred and sixty seven plots were completed by mid 1997 (see Table 4.15 for vegetation and treatment summaries), in which all eleven identified vegetation communities were sampled. Analysis of precision showed approximately 16% precision for presence/absence data and 12% precision for the pellet group counts (both at 95% level of probability).

Table 4.5 Summary figures for calculation of precision for presence/absence of pellet groups from pilot study and overall precision for all faecal observation plots. The pilot study was an initial series of 40 plots used to calculate approximate total plots required for estimating presence or absence within Isolated Hill Scenic Reserve. The formula follows Baddeley (1985).

Precision	Number of plots	Frequency of presences	Required number of plots
Pilot			
10%	40	0.675	658
15%	40	0.675	293
20%	40	0.675	165
Overall			
16%	267	0.633	

Pellet density data were converted to groups per hectare for each vegetation community, then analysed using two-way analysis of variance to investigate treatment and habitat effects. For these analyses the number of faecal pellet groups per plot were log-transformed to ensure heterogeneity of variances.

4.1.4 Habitat parameters

Habitat parameters were calculated from measurements taken during vegetation sampling, from data in Hayward (1985) and Cochrane (1994), and from hunting data

provided by the Department of Conservation. Data were tabulated for later analyses in habitat selection models. The parameters can be broadly classified into six groups:

a) diversity or dominance type measures (total species diversity, browse and seedling tier species diversity, mean number of species per vegetation quadrat, Berger-Parker dominance index, and Margalefs index);

b) cover values of specific dietary components (total monocotyledon cover, broadleaf cover as a percentage of total cover, broadleaf cover in the browse and seedling tier (from ground to two metres), broadleaf cover in the browse and seedling tier as a percentage of tier cover, mahoe cover as a percentage of total cover, mahoe cover in the browse and seedling tier, mahoe cover in the browse and seedling tier as a percentage of tier cover);

c) cover values of principal dietary species as total cover and browse and seedling cover (from Hayward, (1985) and Cochrane, (1994));

d) cover values of unpreferred species (*Nothofagus* percentage of total cover, *Nothofagus* percentage cover in the browse and seedling tier);

e) physical factors (aspect, altitude, slope) and vegetation type areas (the area of each community type in Isolated Hill Scenic Reserve);

f) vegetative cover and hunting difficulty values (vegetative cover is expressed as a percentage of the highest cover vegetation type, kanuka; hunting difficulty is a rank difficulty as rated by Department of Conservation hunters (vegetation communities ranked between 1 (easiest) and 11 (most difficult), see chapter 5 for a full description).

Table 4.6 Summary figures for calculation of precision for pellet groups from pilot study and overall precision for all faecal observation plots. The pilot study was an initial series of 40 plots used to calculate approximate total plots required for estimating an overall abundance of faecal groups. The overall value represents the percentage precision for the study using the formula presented by Neff (1968).

Precision	Number of plots	$\bar{x}$	s^2	$t_{(\alpha=0.05)}$	Required number of plots
Pilot					
10%	40	2.225	9.974	2.021	823
15%	40	2.225	9.974	2.021	366
20%	40	2.225	9.974	2.021	206
Overall					
12%	267	1.76	6.07	1.96	

4.1.5 Habitat selection models

Analysis of habitat selection used Spearman rank correlation and multiple regression to compare selection data on goat habitat use (from direct observation and faecal data) to a range of habitat parameters (section 4.1.4). Because of the large number of multiple correlations made, the significance level for the correlations was set at 0.0003. A second analysis was made excluding the subalpine community. The community was excluded as its high monocotyledon cover confounded several of the site variables (vegetative cover, palatability).

Multiple regression was used to fit data to two-, three-, and four-variable models in an attempt to find predictors for habitat selection data. For all models sub-set regression was utilised within COPLOT (Cohort software, Berkeley, California). This method allowed calculation of all combinations of a set number of independent variables. The five highest coefficient of determination models from each of two, three, and four variable analyses were used for subsequent analysis. The number of models evaluated (using 24 predictors) were 2-variable, 276; 3-variable, 2024; 4-variable, 10 626.

4.1.6 Habitat suitability index – Novellie and Winkler model

Novellie and Winkler (1993) proposed a simple habitat suitability index (HSI) (Equation 2.6) that weighted the preference for a particular species by the proportion of total cover of that species. The individual HSI scores were then summed for each habitat type.

Cochrane (1994) collected rumens from 50 feral goats in Isolated Hill Scenic Reserve as a part of an investigation of feral goat impacts in the reserve. The contents of those 50 stomachs were used as the basis for calculating preference ratings. Preference ratings for individual food items were calculated using a modified version of Ivlev's electivity index (Nugent, 1990). Ivlev's electivity index is normally:

$$E = \frac{(\chi_i - \rho_i)}{(\chi_i + \rho_i)} \qquad \text{Eq. 4.1}$$

Where:

χ_i = food *i* as a proportion of total food consumed
ρ_i = i as availability in the environment

Equation 4.1 yields a value between –1 and 1, with positive values indicating preference, negative values avoidance. The modified version is:

$$\hat{E} = \frac{(E+1)}{2} \qquad \text{Eq. 4.2}$$

Where E is the Ivlev's electivity score

This yields a value between 0 and 1, values less than 0.5 indicate avoidance, values greater than 0.5 indicate preference. This value is then multiplied by the percentage availability of food *i* in the habitat (refer equation 2.6), and the values for all individual food items are summed to yield a habitat suitability index.

Initially three different habitat suitability index scores were calculated on a per hectare basis (calculated per hectare to reflect the energetic cost of search time by foraging animals). The first model was a habitat scale score in which preferences were calculated for the percentage cover of each food type in that community, then multiplied by the percentage cover of the food type within that vegetation community (for example *Griselinia littoralis* has a mean index of 7.18 in the matai community and 13.71 in the broadleaf community, reflecting the different covers and preference scores for *G. littoralis* in the two communities). The second model was a landscape scale score in which preferences were calculated for individual food types on the basis of percentage cover for the entire reserve and then multiplied by their cover in each individual community (for example preference for *G. littoralis* was not recalculated for individual vegetation communities but had a single value of 0.89 for the entire scenic reserve. The final model was a diet contribution score in which no preferences were calculated. Instead percentage contribution to diet was weighted by percentage cover of individual food types in each vegetation community.

The models were also recalculated to incorporate the area of different vegetation communities (transformed by multiplying the habitat suitability index by $\log_{10}$ of community area). This was calculated to allow for potential knowledge by the feral goats of the size of each vegetation community, and hence total potential resource. Habitat suitability indices were then compared to observed habitat selection (direct observation and faecal pellet counts) using Spearman rank correlation.

4.2 Results

4.2.1 Observation of habitat selection at Isolated Hill Scenic Reserve

4.2.1.1 Overall and treatment effects (direct observation and pellet group densities)

A total of 103 goat mobs were observed at Isolated Hill Scenic Reserve during the period November 1994 to October 1996 (pre-control treatment) (Table 4.7). The 103 mobs constituted 200 individual goats. During the post-control treatment period (December 1996 – July 1997) 44 mobs of goats were observed, constituting 99 individual goats (Table 4.7).

The greatest numbers of mobs during the pre-control treatment were observed in broadleaf, grass/scrubland, and mahoe-titoki vegetation communities. These observations accounted for 85.4% of all mobs recorded (Table 4.7). Hall's totara, red beech, and subalpine communities had no mobs recorded in them during this period. In contrast, during the post-control period broadleaf, grass/scrubland, and mahoe-titoki communities accounted for 70.4% of all observed mobs (Table 4.4). Vegetation types that did not have mobs recorded in them were Hall's totara, red beech, matai, and mountain beech (matai and mountain beech communities accounted for 2.9% and 1.9% of the observed mobs during the pre-control period).

Table 4.7 Feral goat counts at Isolated Hill Scenic Reserve. Figures are percentage of total observations for goat groups (mobs).

Vegetation community	Group Counts	
	Pre-control	Post-control
Broadleaf	32.0	25.0
Grass/scrubland	29.1	31.8
Mahoe-Titoki	24.3	13.6
Bluffs and Screes	5.8	11.4
Improved grassland	2.9	4.5
Matai	2.9	0
Mountain Beech	1.9	0
Kanuka	1.0	4.5
Hall's totara	0	0
Red Beech	0	0
Subalpine	0	9.1

A total of 267 faecal pellet plots were completed during the study (Table 4.8). In these plots a total of 470 fresh pellet groups were recorded. This gave an overall value of 1.76 faecal pellet groups per plot or 704 fresh pellet groups per hectare. Seventy three percent of faecal pellet plots were measured within forest vegetation communities. The

majority of these were in mahoe-titoki (25 % of total plots) and broadleaf communities (20 % of total plots).

Table 4.8 Summary figures for number of faecal quadrats measured and number of fresh pellet groups recorded at Isolated Hill Scenic Reserve. Number of quadrats is also summarised for pre and post treatment.

Community type	Total quadrats	Total pellet groups	Number Pre-control quadrats	Number Post-control quadrats
Broadleaf	53	148	25	28
Grass scrubland	23	29	5	18
Mahoe-titoki	66	141	35	31
Bluffs and Screes	24	43	21	3
Improved grassland	16	15	8	8
Matai	20	40	13	7
Mountain Beech	14	11	8	6
Kanuka	12	16	6	6
Hall's totara	15	16	11	4
Red Beech	14	3	8	6
Subalpine	10	8	4	6
Total	**267**	**470**	**144**	**123**

The number of feral goat mobs observed per day (Fig. 4.1) was highest in March 1996. Mob numbers were also high for the following months, January 1996, September 1995, August 1996, October 1996, August 1995, and February 1996. There was no clear trend in the number of observed mobs during the period of the study, although generally few goat mobs were observed subsequent to the control treatment of November 1996. Pooling of monthly observations of mob numbers (Fig. 4.2) reveals an interesting trend. Observed mobs are at their lowest during April to July which may reflect two possibilities, a) feral goats are less mobile or less detectable during this period, or b) observer ability is reduced during autumn and winter months. Generally, observed mobs were at highest numbers during the period August to December. The obvious exception to this is November when observed mob numbers were very low. One possible explanation for this is increased use of the reserve for recreational hunting in early November (Canterbury province has a public holiday in early November) which may lead to hunter induced avoidance (recreational hunters frequent the reserve in high numbers at two times of the year: a) during April for the red deer stag roar, and b) during November (Author, *pers. obs.*)).

Mean number of goats per mob revealed no clear trend during the period of a year (Fig. 4.3). Mean number per mob ranged from one during May to 2.55 in March. There was

no significant difference in the number of goats per mob pre-treatment and post-treatment (P=0.3).

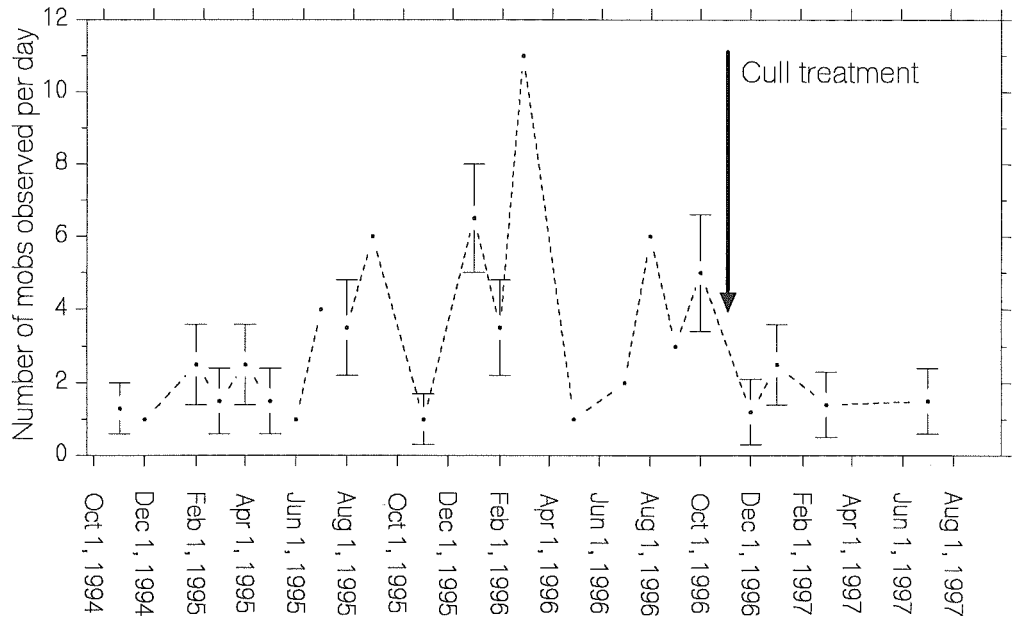


Figure 4.1 Number of mobs observed per day of effort November 1994 – July 1997 at Isolated Hill Scenic Reserve. Figures are presented with ± 1 S.E.. Control treatment in November 1996 is indicated.

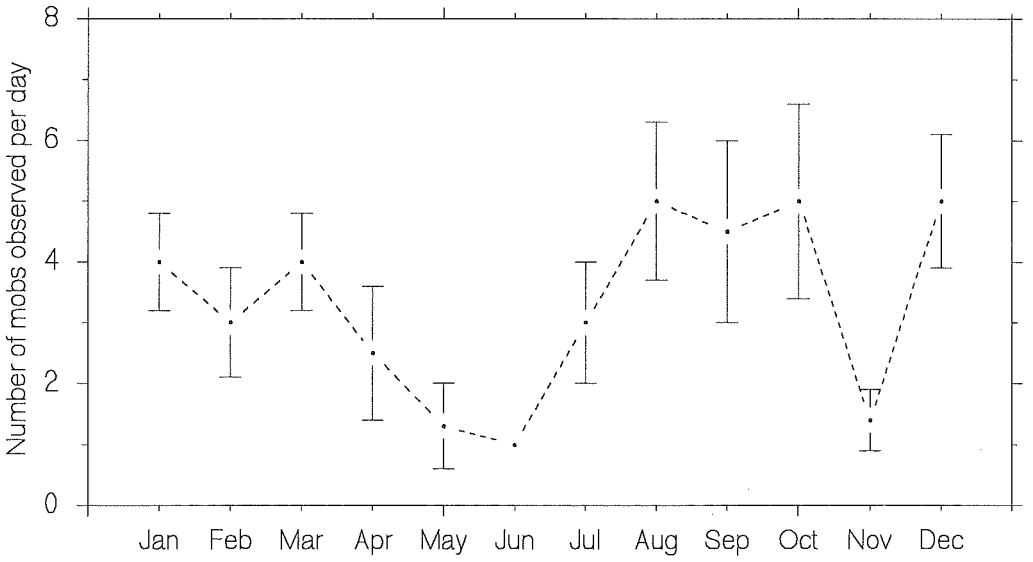


Figure 4.2 Mean number of mobs observed per day by month at Isolated Hill Scenic Reserve 1994 - 1997. Data are pooled for pre and post-treatment. Figures are the mean number ± 1 S.E.

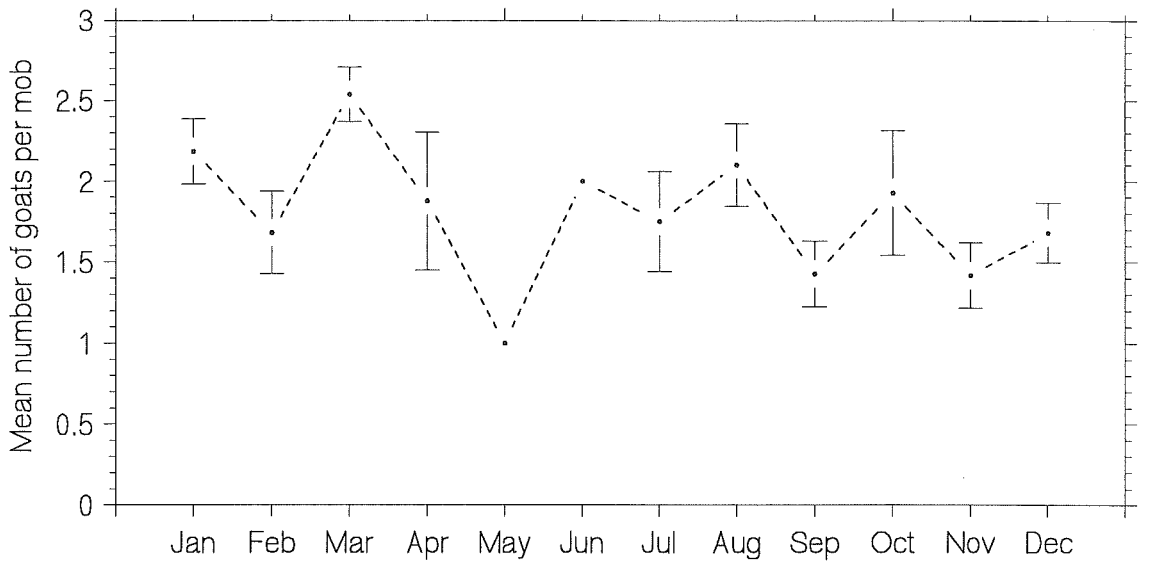


Figure 4.3 Mean number of goats per mob by month at Isolated Hill Scenic Reserve 1994-1997. Figures are the mean number ± 1 S.E.

Habitat selection by feral goats was calculated as the density of mobs per hectare for each identified vegetation community. Density of mobs was compared by habitat (Fig. 4.4) and by pre and post-control treatment (Fig. 4.6). Similarly, pellet group densities were also compared by habitat and pre and post-control treatment (Figs. 4.5 and 4.7).

Pooled habitat data (direct observation) reveals clear spatial trends for habitat selection at Isolated Hill Scenic Reserve (Fig. 4.4). Two communities, Hall's totara and red beech, had no feral goats observed within them for the duration of the study. Mountain beech and subalpine communities recorded low densities of feral goats, whilst three vegetation types, kanuka, improved grassland, and grass/scrubland recorded mid-level densities of 0.09 – 0.10 mobs per hectare. Four communities had relatively high densities: bluffs and screes, matai, mahoe-titoki, and broadleaf. Broadleaf had the highest average density of 0.20 mobs per hectare.

Analysis of pooled mean pellet group numbers per hectare showed that faecal pellet groups are heterogeneously distributed within Isolated Hill Scenic Reserve (Fig. 4.5).

The mean number ranges from 85.7 (± 49.5 1S.E.) groups per hectare for the red beech vegetation community to 1096.3 (± 90.1 1S.E.) groups per hectare for the broadleaf vegetation community. The next lowest and highest vegetation communities are mountain beech (314.3 ± 94.8 groups per hectare) and mahoe-titoki (854.5 ± 72 per hectare).

Direct observation and faecal pellet density data were correlated ($P<0.01$). Both sets of data showed similar trends in terms of relative use (Figs. 4.4 and 4.5). However pellet density data recorded the use of Hall's totara and red beech communities whereas direct observation did not record use of these communities. Differences were also recorded in the relative use of improved grassland and grass/scrubland communities. Direct observation recorded similar use for the two communities, whereas pellet density data suggested that the grass/scrubland community was more utilised than the improved grassland community.

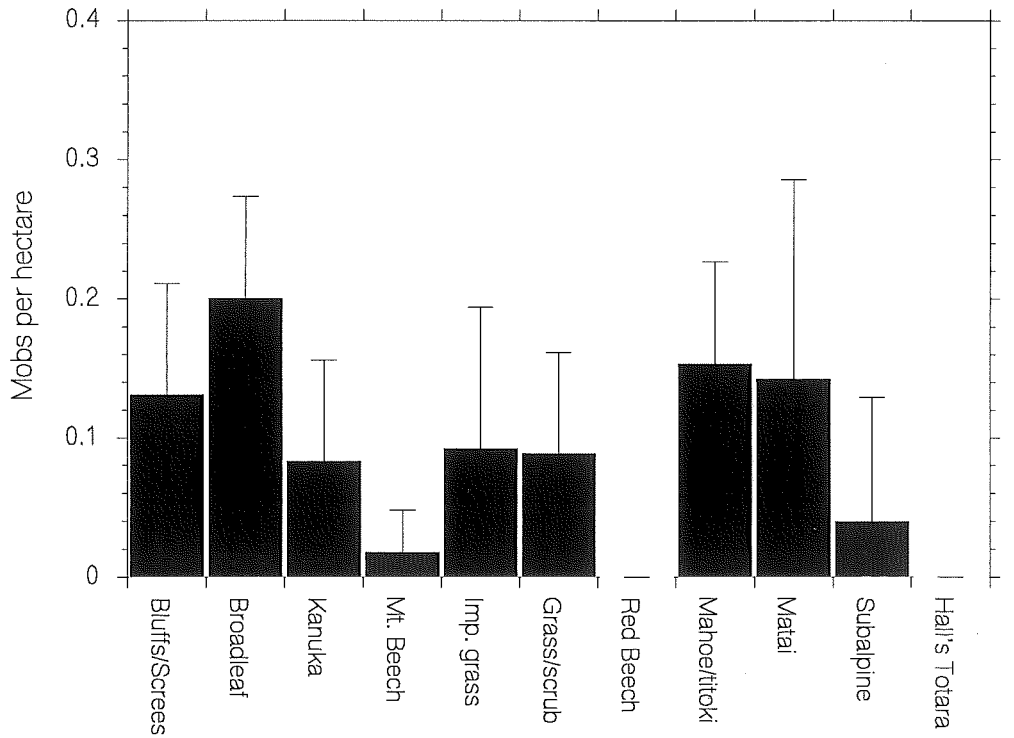


Figure 4.4 Mean density of goat mobs per hectare for pooled habitat selection figures at Isolated Hill Scenic Reserve. Figures are pooled across season and treatment. Figures are the mean density per hectare ± 1 S.E.

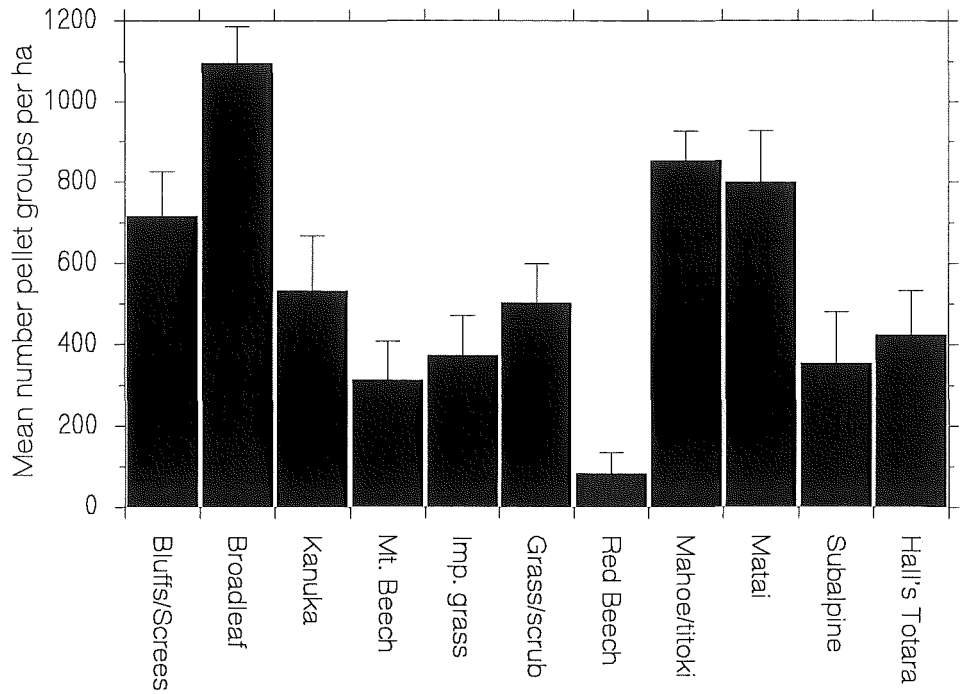


Fig 4.5 Pooled pellet group density data for vegetation communities at Isolated Hill Scenic Reserve 1995-1997. Figures presented are mean number per hectare ± 1 S.E.

Habitat selection pre and post-control treatment revealed contrasting trends (Fig 4.6). For the pre-control treatment communities can be subjectively divided into four groups (Fig. 4.6). No use was recorded in red beech, subalpine and Hall's totara vegetation. Low use was recorded for kanuka and mountain beech, while medium levels of use were recorded for improved grassland and grass/scrubland. High levels of use were recorded for bluffs and screes, mahoe-titoki, broadleaf, and matai communities. The post-control habitat selection (Fig. 4.6) differs in that communities can be divided into three groups. Zero density was recorded for mountain beech, red beech, matai and Hall's totara vegetation. A second group consists of bluffs and screes, broadleaf, grass/scrubland, and mahoe titoki communities. The third group (high use) consists of kanuka, improved grassland, and subalpine communities. Of particular interest are the changes in relative use pre and post-control. Six of the communities (bluffs and screes, mahoe-titoki, Hall's totara, red beech, mountain beech and grass/scrubland) change little in terms of their relative densities pre and post-control. Three communities (subalpine, kanuka, and improved grassland) have higher relative densities post-control

than pre-control. Conversely, broadleaf and matai communities have lower relative densities post-control than pre-control (Fig. 4.6).

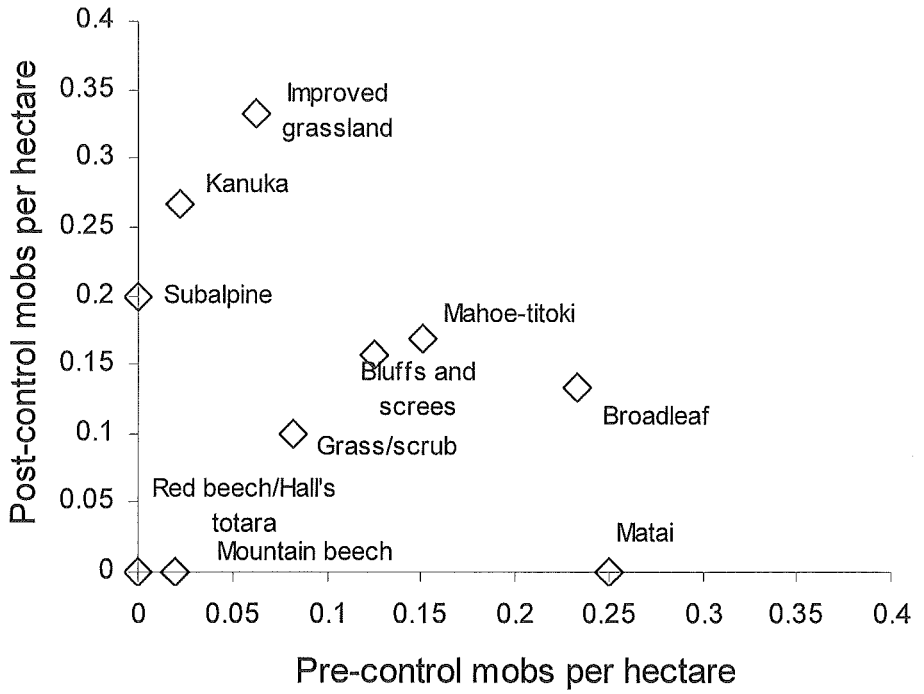


Figure 4.6 Mean density of goat mobs per hectare for pre-control and post-control treatment habitat selection figures at Isolated Hill Scenic Reserve.

Comparison of the two separate treatments pre and post-control for the pellet density data shows a quite different trend (Fig. 4.7). Figure 4.7 reveals non-homogeneous use of vegetation communities at Isolated Hill Scenic Reserve, although differences between communities in the post-control treatment are less pronounced. The pre-control treatment ranges from 0 pellet groups per hectare for red beech vegetation to 1936 ± 176 groups per hectare for broadleaf vegetation. In contrast the post-control treatment ranges from 100 ± 70.7 groups per hectare for pasture to 600 ± 200 groups per hectare for kanuka vegetation. Of note is the increase in pellet groups in the red beech and kanuka communities in the post-control treatment above the level observed in the pre-control treatment (red beech, pre-control 0 pellet groups per hectare, post-control 200 ± 115.5; kanuka, pre-control 466.7 ± 176.4 pellet groups per hectare, post-control 600 ± 200). Analysis of percentage change shows that that a 60.2% drop has occurred in the number of faecal groups recorded. The greatest reductions are in improved grassland (84.6%), Hall's totara (81.7%), broadleaf (80.8%), and matai (79.4%) communities.

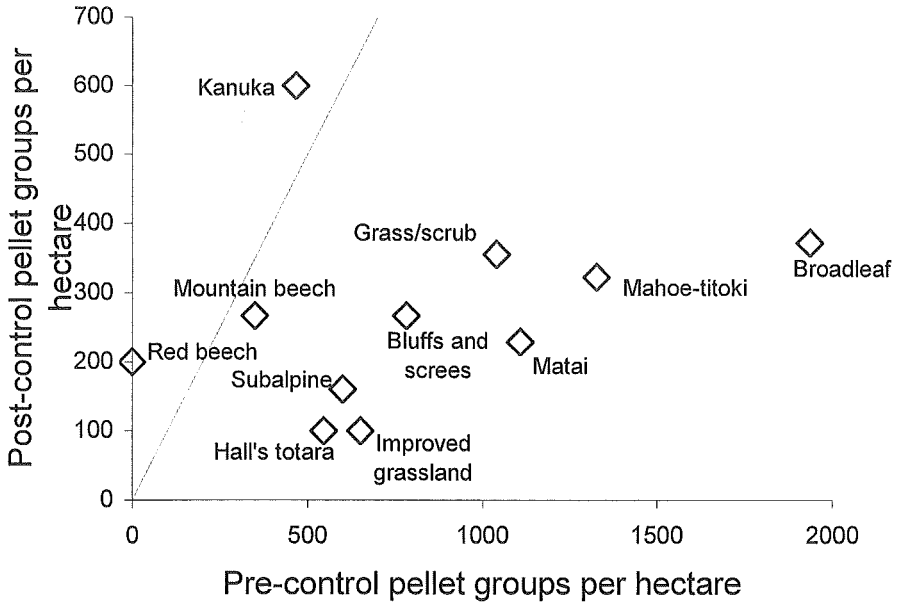


Fig 4.7 Faecal pellet group numbers for vegetation communities at Isolated Hill Scenic Reserve pre-control and post-control. Figures presented are mean number per hectare. The dotted represents x=y (*i.e.* no change).

Two-way analysis of variance (ANOVA) was used to test for significant habitat and treatment effects at Isolated Hill Scenic Reserve for direct observation and pellet density data (Tables 4.9 and 4.10). The two-way ANOVA for direct observation (Table 4.9) was calculated for eight communities only, the reason for this was the poor replication of three communities in one or other of the treatments. The eight communities included were bluffs and screes, broadleaf, kanuka, mountain beech, grass/scrubland, red beech, mahoe-titoki, and matai. Improved grassland, subalpine, and Hall's totara vegetation were excluded from the analysis. The analysis revealed no significant effect for treatment (P=0.637) or vegetation type (P=0.391), and no significant interaction effect (P=0.520).

Table 4.9 Two way analysis of variance of goat density (direct observation) for treatment and habitat selection at Isolated Hill Scenic Reserve for direct observation pre and post-control treatments. No significant differences are apparent.

Source of variation	**SS**	**df**	**MS**	**F**	**p-level**
Treatment	0.00118	1	0.00118	0.22302	0.637
Habitat	0.03915	7	0.00559	1.06103	0.391
Interaction	0.03267	7	0.00467	0.88533	0.520
Residuals	0.80119	152	0.00527		
Total	0.87419	167			

Two-way analysis of variance was also applied to the pellet density data (Table 4.10). In contrast to the direct observation analysis a significant treatment effect ($P < 0.05$) was found. However, on applying a post-hoc test for significant differences (Tukey HSD) (Table 4.11) it is apparent that while there is a significant difference between the two treatments that this cannot be applied to all communities. Two communities show significant differences between the two treatments. Both broadleaf ($P < 0.001$) and mahoe-titoki ($P < 0.001$) communities have significantly lower log mean pellet group counts per hectare post-control than pre-control (Table 4.11). Within the pre-control treatment significant differences are apparent between broadleaf vegetation and bluffs and screes ($P < 0.01$), and broadleaf vegetation and red beech ($P<0.001$) (Table 4.11). Figure 4.8 shows the log mean number of faecal groups per plot by habitat and reveals the trends cited earlier (pellet groups per hectare) and also shows the differences apparent from the ANOVA.

Table 4.10 Two way analysis of variance of treatment and habitat at Isolated Hill Scenic Reserve for pellet density data pre and post cull. Analysis reveals significant differences between treatments, although no general pattern is apparent pre and post treatment for all vegetation communities.

Source of variation	SS	df	MS	F	p-level
Treatment	1.32446	1	1.32446	18.59988	0.00002
Habitat	2.45438	10	0.24544	3.44678	0.00030
Interaction	1.50066	10	0.15007	2.10743	0.02451
Residuals	17.44596	245	0.07121		
Total	22.72546	266			

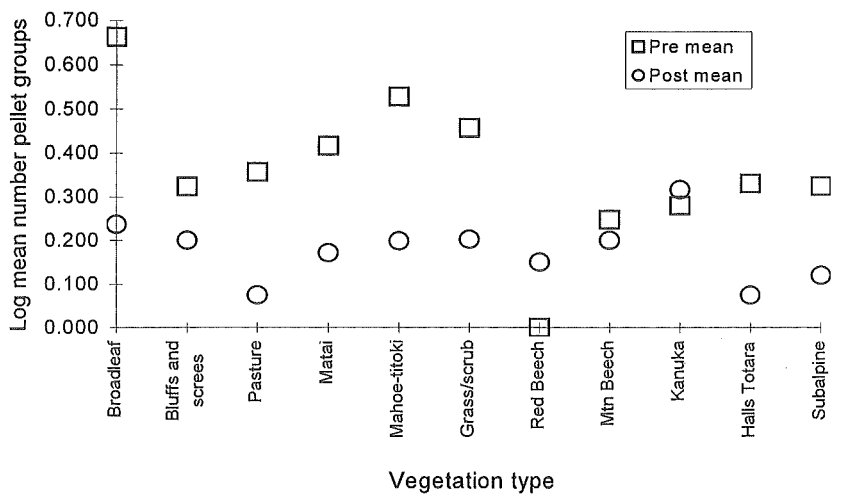


Fig 4.8 Comparison of mean number of pellet groups per quadrat for pre and post-control treatments.

Table 4.11 Probability values for post-hoc Tukey HSD test for significant difference between and within treatments. Significance is indicated by bold emphasis. Individual communities have been compared between treatments, within treatment all communities are compared.

Treatment	Vegetation community	Pre-control treatment											Post-control treatment										
		Broadleaf	Bluffs & Screes	Pasture	Matai	Mahoe-titoki	Grass scrub	Red Beech	Mtn Beech	Kanuka	Hall's Totara	Subalpine	Broadleaf	Bluffs & Screes	Pasture	Matai	Mahoe-titoki	Grass scrub	Red Beech	Mtn Beech	Kanuka	Hall's Totara	Subalpine
Pre-control	Broadleaf																						
Pre-control	Bluffs & Screes	**0.007**																					
Pre-control	Pasture	0.786	1.000																				
Pre-control	Matai	0.744	1.000	1.000																			
Pre-control	Mahoe-titoki	0.979	0.639	1.000	1.000																		
Pre-control	Grass scrub	1.000	1.000	1.000	1.000	1.000																	
Pre-control	Red Beech	**0.000**	0.690	0.492	0.197	0.013	0.469																
Pre-control	Mtn Beech	0.204	1.000	1.000	1.000	0.887	1.000	0.966															
Pre-control	Kanuka	0.647	1.000	1.000	1.000	0.993	1.000	0.972	1.000														
Pre-control	Hall's Totara	0.315	1.000	1.000	1.000	0.983	1.000	0.650	1.000	1.000													
Pre-control	Subalpine	0.977	1.000	1.000	1.000	1.000	1.000	0.985	1.000	1.000	1.000												
Post-control	Broadleaf	**0.000**	1.000	1.000	0.987	0.006	1.000	0.978	1.000	1.000	1.000	1.000											
Post-control	Bluffs & Screes	0.881	1.000	1.000	1.000	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000										
Post-control	Pasture	0.002	0.965	0.884	0.587	0.092	0.804	1.000	1.000	1.000	0.953	1.000	1.000	1.000									
Post-control	Matai	0.082	1.000	1.000	0.986	0.632	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000								
Post-control	Mahoe-titoki	0.000	0.997	1.000	0.899	**0.000**	0.997	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000							
Post-control	Grass scrub	0.000	0.999	1.000	0.916	0.041	0.997	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000						
Post-control	Red Beech	0.115	1.000	0.999	0.985	0.667	0.973	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000					
Post-control	Mtn Beech	0.264	1.000	1.000	0.999	0.876	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
Post-control	Kanuka	0.816	1.000	1.000	1.000	0.999	1.000	0.907	1.000	1.000	1.000	1.000	1.000	1.000	0.995	1.000	1.000	1.000	1.000	1.000			
Post-control	Hall's Totara	0.202	1.000	0.998	0.974	0.706	0.921	1.000	1.000	1.000	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000		
Post-control	Subalpine	0.156	1.000	0.999	0.982	0.694	0.931	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	

4.2.1.2 Seasonal habitat selection (direct observation)

Summation of seasonal feral goat mob numbers (Table 4.12) reveals different patterns of selection during different seasons. Grassland vegetation (grass/scrubland and improved grassland) peaked in selection during autumn and spring seasons (combined 38.5% and 63.6% respectively), although selection was also high during the winter season (combined 36%)(Table 4.5). Selection of broadleaf and mahoe-titoki communities (both reported as preferred habitat for feral goats (Hayward, 1985)) recorded peak selection during summer with 62.3% of all mobs observed in these two types. In autumn selection had fallen to 51.3%; winter and spring recorded the same level of selection at 36%. Mountain beech and kanuka vegetation were only selected during summer months, while two communities (red beech and Hall's totara) were not selected in any season.

Table 4.12 Seasonal feral goat counts at Isolated Hill Scenic Reserve. Figures are percentage of total for goat groups (mobs). A total of 61 groups (120 individuals) were observed during summer, 39 groups (91 individuals) during autumn, 25 groups (51 individuals) during winter, and 22 groups (37 individuals) during spring.

Vegetation Community	Summer Group counts	Autumn Group counts	Winter Group counts	Spring Group counts
Broadleaf	34.4	38.5	16.0	18.2
Grass scrubland	18.0	38.5	28.0	50.0
Mahoe-titoki	27.9	12.8	20.0	18.2
Bluffs/Screes	4.9	10.3	16.0	0
Improved grassland	0	0	8.0	13.6
Matai	0	0	12.0	0
Mountain Beech	3.3	0	0	0
Kanuka	4.9	0	0	0
Hall's totara	0	0	0	0
Red Beech	0	0	0	0
Subalpine	6.6	0	0	0

Comparison of seasonal densities (Figs. 4.9 – 4.12) revealed clear temporal and spatial trends in selection of vegetation communities by feral goats. Summer habitat selection (Fig. 4.9) showed seven vegetation communities that were selected. Low use types were mountain beech, grass/scrubland, mahoe-titoki, subalpine, and bluffs and screes vegetation. High use communities were kanuka and broadleaf vegetation. The communities that were utilised cover a range of aspects and altitudes, which suggests that generally climate does not influence habitat selection during summer. This is in contrast to winter (Fig. 4.11) when the subalpine community was avoided.

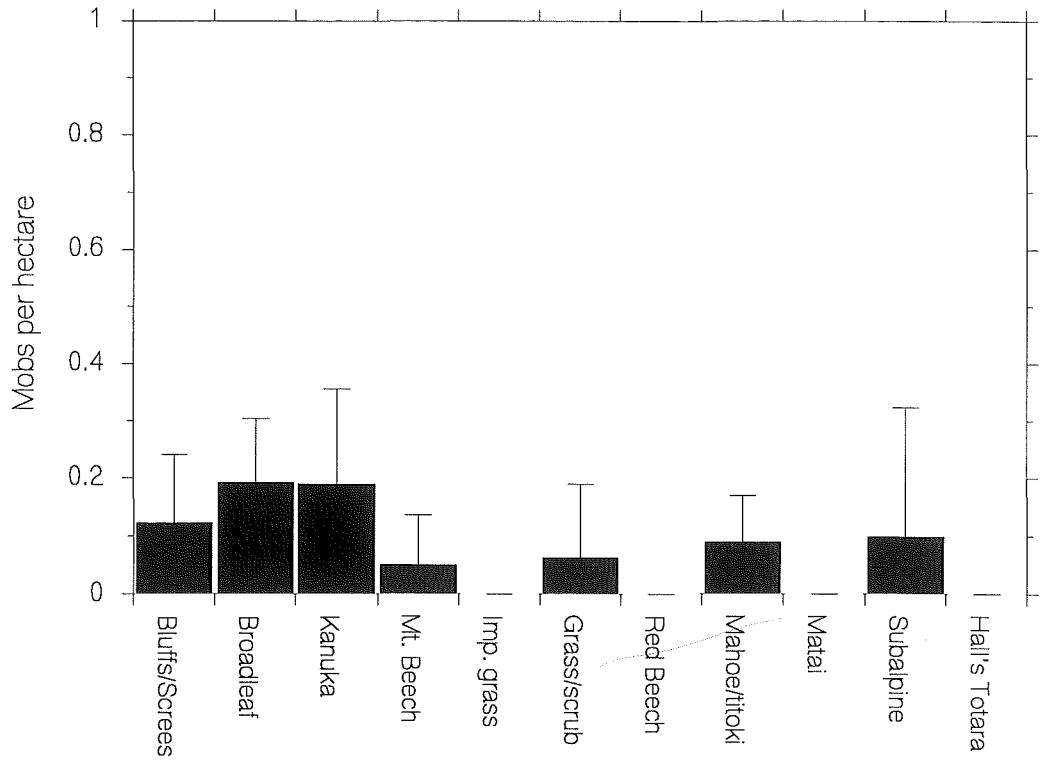


Figure 4.9 Seasonal mean density of goat mobs per hectare for summer habitat selection figures at Isolated Hill Scenic Reserve. Figures are the mean density per hectare ± 1 S.E.

Autumn habitat selection (Fig. 4.10) showed only four vegetation communities that were selected. Of the four types bluffs and screes, grass/scrubland, and mahoe-titoki recorded low to mid level use. Only broadleaf vegetation had a high level of use. Of interest three of the four communities selected have high levels of palatable plant species within them, potentially indicating that feral goats are targeting communities that have higher food reward within them.

Winter habitat selection (Fig. 4.11) revealed use of six vegetation communities. Low use was recorded for grass/scrubland, and mahoe-titoki vegetation, mid-levels of use for broadleaf vegetation, and high levels of use were recorded for bluffs and screes, improved grassland, and matai vegetation. Winter habitat selection figures were generally highly variable reflecting in part the less intense sampling of this season throughout the study.

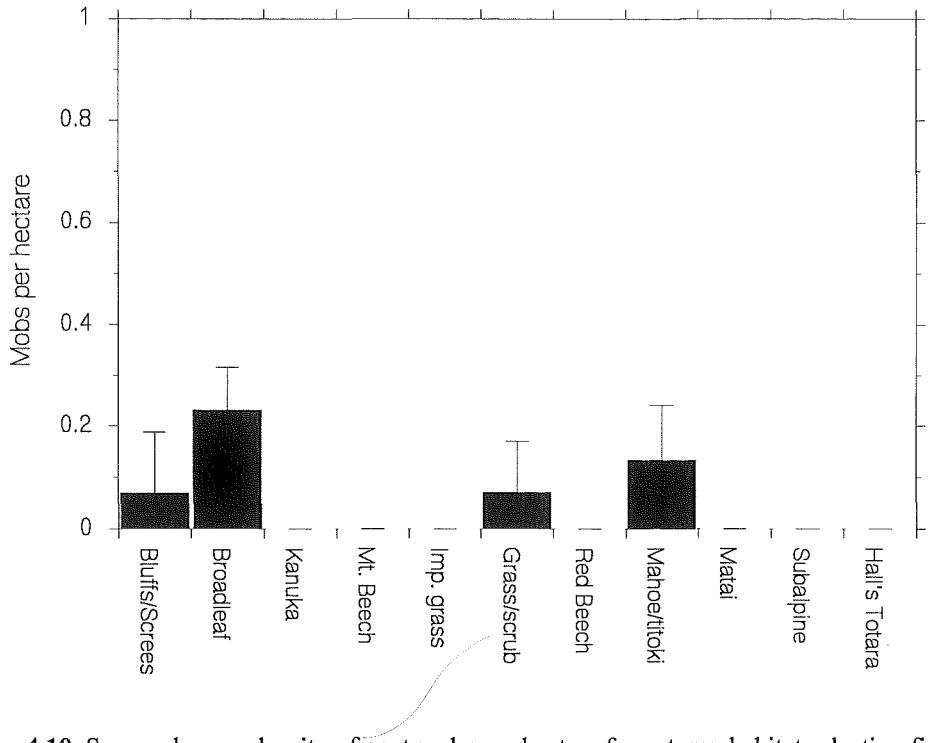


Figure 4.10 Seasonal mean density of goat mobs per hectare for autumn habitat selection figures at Isolated Hill Scenic Reserve. Figures are the mean density per hectare ± 1 S.E.

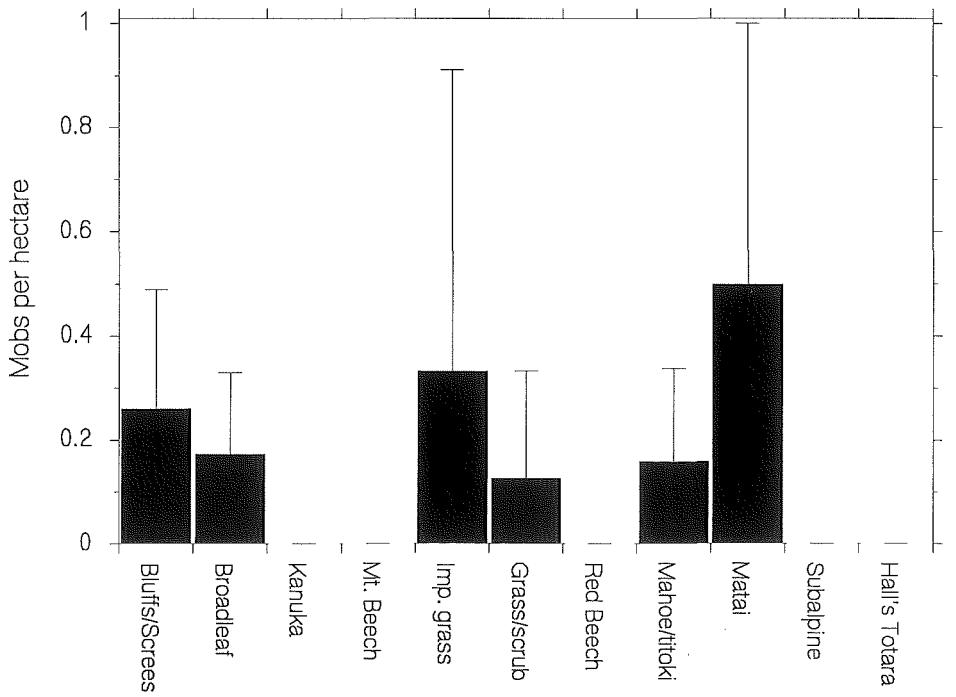


Figure 4.11 Seasonal mean density of goat mobs per hectare for winter habitat selection figures at Isolated Hill Scenic Reserve. Figures are the mean density per hectare ± 1 S.E.

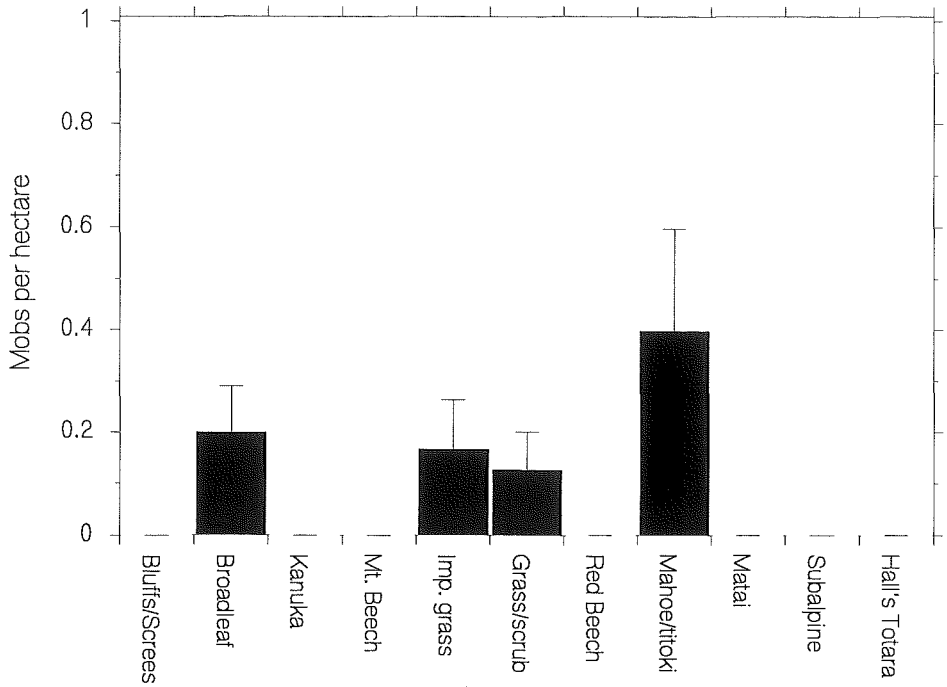


Figure 4.12 Seasonal mean density of goat mobs per hectare for spring habitat selection figures at Isolated Hill Scenic Reserve. Figures are the mean density per hectare ± 1 S.E.

Spring habitat selection (Fig. 4.12) showed four selected vegetation communities. Vegetation communities were subjectively divided into three groups, no use, low use (broadleaf, improved grassland and grass/scrubland) and high use (mahoe-titoki). The increased usage of grassland communities potentially reflects spring pastoral growth.

Differences in seasonal habitat selection were analysed using two-way ANOVA to investigate seasonal and habitat effects. Again only a subset of vegetation communities were analysed (broadleaf, kanuka, mountain beech, grass/scrubland, red beech, and mahoe-titoki) due to poor replication of vegetation communities throughout seasons. Two-way ANOVA (Table 4.13) revealed no significant effect due to season, but did show a significant ($P < 0.01$) effect due to habitat. Interaction effects were not significant ($P = 0.833$).

Table 4.13 Two way analysis of variance of season and habitat selection at Isolated Hill Scenic Reserve.

Source of variation	SS	df	MS	F	p-level
Season	0.00385	3	0.00128	0.25552	0.857
Habitat	0.09905	5	0.01981	3.94593	0.002
Interaction	0.04847	15	0.00323	0.64360	0.833
Residuals	0.58232	116	0.00502		
Total	0.73369	139			

Post-hoc analysis of differences (Table 4.14) revealed that significant differences were attributable to differences in the selection of mahoe-titoki and red beech vegetation communities. An equivalent analysis of pellet density data was not done as pellet groups were unable to be assigned a specific season in all situations.

Table 4.14 Probability values for post-hoc Tukey HSD test for significant difference between habitats. Significance is indicated by bold emphasis. Values indicate significance level.

Vegetation community	Broadleaf	Kanuka	Mtn Beech	Grass/scrub	Red Beech
Broadleaf					
Kanuka	0.312				
Mtn Beech	0.073	0.999			
Grass/scrub	0.877	0.920	0.710		
Red Beech	0.040	0.991	1.000	0.576	
Mahoe-titoki	1.000	0.289	0.065	0.858	**0.035**

4.2.2 Observation of habitat selection at Black Angel Creek

During the period of the study a total of 55 feral goat mobs were observed in the Black Angel Creek catchment area (Table 4.15), 33 pre-control and 23 mobs post-control. This amounted to 144 feral goats (68 individuals pre-control treatment, 76 individuals post-control treatment). During the pre-control period the greatest percentage of mobs were observed in the scrub/grassland vegetation type (57.6%). This feature remained similar post-control with 52.2% of all observed mobs in this vegetation type. The use of the improved grassland vegetation type changed considerably between the two treatments, 18.2% of observed mobs used this area pre-control, and 34.8% were recorded in this area post-control. In part this may be attributed to a change in the improved grassland environment, areas of which were burnt in September 1996.

Table 4.15 Feral goat counts at Black Angel Creek. Figures are percentage of total goat groups (mobs).

	Group Counts	
Vegetation Type	Pre-kill	Post-kill
Scrub/grassland	57.6	52.2
Improved grassland	18.2	34.8
Kanuka	12.1	4.4
Mountain Beech	12.1	4.4
Subalpine	0	4.4

Comparison of mean densities per hectare in differing vegetation also revealed distinct variation in the habitat selection of feral goats at Black Angel Creek. When all selection figures are considered (Fig. 4.13) two classes of use can be recognised. Low use types are kanuka, mountain beech and subalpine vegetation, high use types are improved grassland and grass/scrubland vegetation. Average density ranged from 0.001 to 0.031 mobs per hectare.

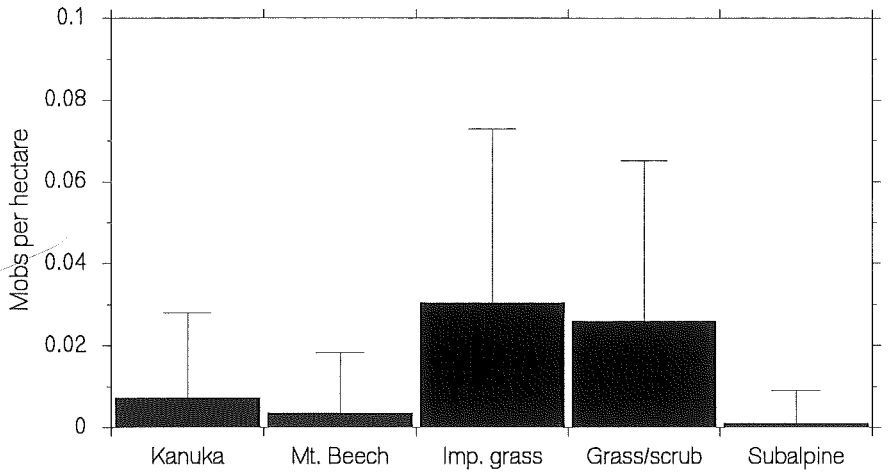


Figure 4.13 Mean density of feral goat mobs for pooled habitat selection figures at Black Angel Creek. Figures are pooled for season and treatment. Figures are the mean density per hectare ± 1 S.E.

Comparison of pre and post-control habitat selection (Fig. 4.14) shows that three vegetation communities (subalpine, scrub/grassland, and mountain beech) had little change in the use made of them by feral goats. Kanuka and grassland vegetation communities recorded larger changes in use pre and post control. The greater use of the grassland community reflects the change in vegetation brought on by fire in early 1996. Feral goats were often observed grazing on new grass growth in the summer of 1996/1997 in areas that had been burnt. The average density of feral goat ranged between zero and 0.027 mobs per hectare pre-control. In the post-control treatment all vegetation types were selected, although three (kanuka, mountain beech, and subalpine vegetation) recorded very low feral goat densities (0.004 mobs per hectare or less). Two vegetation types, improved grassland and grass/scrubland, recorded considerably higher levels of selection (0.042 and 0.024 mobs per hectare respectively). Average density ranged from 0.002 to 0.042 mobs per hectare.

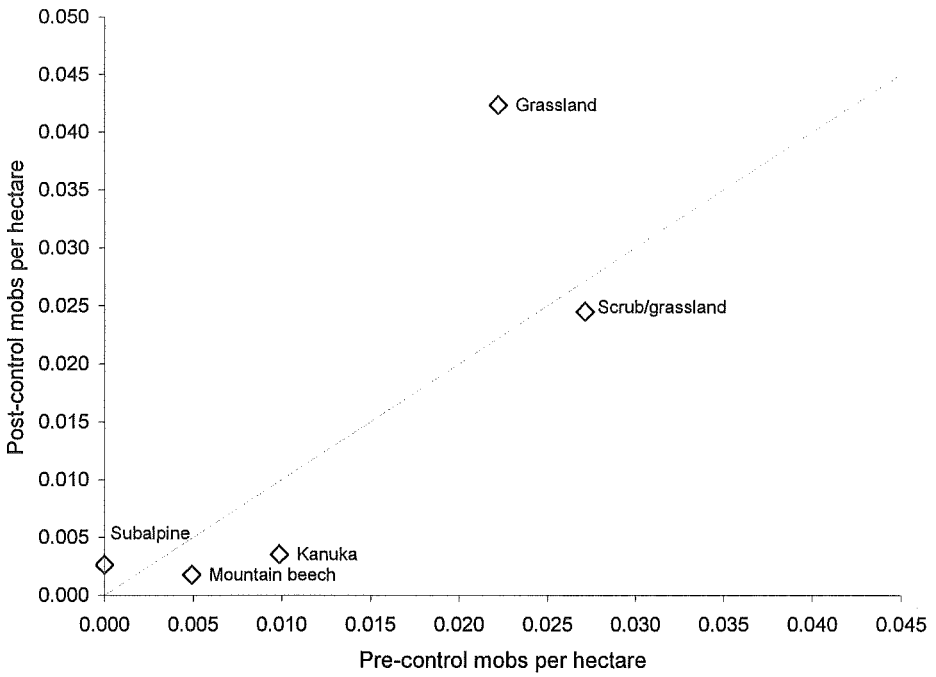


Figure 4.14 Mean density of feral goat mobs for pre-control and post-control treatment habitat selection at Black Angel Creek. Dotted line represents x=y (*i.e.* no change)

Two-way analysis of variance was used to investigate differences in habitat selection between vegetation types and treatments (Table 4.16). No statistically significant result was recorded for treatment, however a statistically significant result did emerge for vegetation type ($P < 0.05$). There was no statistically significant result for an interaction effect.

Table 4.16 Two way analysis of variance for pre and post-cull treatment and habitat at Black Angel Creek. A significant result for habitat was recorded.

Source of variation	SS	df	MS	F	p-level
Treatment	0.000006	1	0.000006	0.031976	0.859
Habitat	0.002141	4	0.000535	2.788151	0.032
Interaction	0.000231	4	0.000058	0.301371	0.876
Residuals	0.014400	75	0.000192		
Total	0.016778	84			

Statistically significant differences in habitat selection were found between improved grassland and mountain beech vegetation, and improved grassland and subalpine vegetation (Table 4.11). Significant differences in habitat selection were also observed between subalpine and scrub/grassland communities. Kanuka was also nearly significantly different from improved grassland ($P = 0.053$).

Table 4.17 Post-hoc Duncan's range test for significant differences between habitats. Significance is indicated by bold emphasis.

Vegetation type	Kanuka	Mtn Beech	grassland	Scrub/grass
Kanuka				
Mtn Beech	0.769			
Grassland	0.053	**0.032**		
Scrub/grassland	0.090	0.060	0.725	
Subalpine	0.655	0.854	**0.023**	**0.046**

4.2.3 Habitat parameter measurements

Habitat parameter values were collected for all eleven vegetation communities identified at Isolated Hill Scenic Reserve. Habitat parameter values are listed in tables 4.18a-d.

Table 4.18a Site diversity and dominance values at Isolated Hill Scenic Reserve.

Vegetation community	Total diversity	Browse and seedling tier diversity	Mean number of species per plot	Berger-Parker score	Margalefs' index
Broadleaf	53	48	16.3	0.32	3.25
Grass scrubland	44	44	14.1	0.35	3.31
Mahoe titoki	42	33	14.6	0.39	3.02
Bluffs & Screes	21	19	6.6	0.54	2.18
Improved grassland	48	48	11.2	0.53	2.32
Matai	64	62	22.1	0.47	4.44
Mountin Beech	60	55	19.4	0.52	3.82
Kanuka	73	67	18.5	0.52	2.96
Hall's totara	24	18	11.6	0.81	2.49
Red Beech	35	33	17.8	0.51	3.53
Subalpine	6	6	4.7	0.44	0.8

Table 4.18b Site broadleaf (*Griselinia littoralis*) and mahoe (*Melicytus ramiflorus*) values at Isolated Hill Scenic Reserve.

Vegetation community	Broadleaf % cover - total	Broadleaf cover - browse and seedling	Broadleaf cover - percentage of browse	mahoe cover – percentage of browse	Mahoe cover - total	Mahoe cover – browse and seedling	Monocot cover - total
Broadleaf	20.6	0.3	0.9	0.6	18	0.2	7.9
Grass scrubland	0.5	0.5	0.5	0	0	0	46.1
Mahoe titoki	3.6	1.4	6.2	0.4	13.8	0.1	3.9
Bluffs & Screes	0.5	0	0	0	0	0	7.1
Improved grassland	0	0	0	0	0	0	57.2
Matai	8.7	0.1	0.4	0.4	7.6	0.1	4.3
Mountain Beech	1.2	0.5	0.8	1	14.8	0.6	0.2
Kanuka	7.4	2.5	2.6	1.1	1.8	1	5.4
Hall's totara	0.5	0	0	0	0	0	4
Red Beech	1.7	0.1	0.1	0	0	0	0.3
Subalpine	0	0	0	0	0	0	100

Table 4.18c Site palatable species cover and *Nothofagus* spp. cover values for correlation with feral goat habitat selection at Isolated Hill Scenic Reserve. Hayward (1985) and Cochrane (1994) were used to define palatable species. Cover values are calculated from this study.

Vegetation community	Total cover (diet from Cochrane, 1994)	Total cover (from Hayward, 1985)	Browse cover (diet from Cochrane, 1994)	Browse cover (from Hayward, 1985)	*Nothofagus* total cover	*Nothofagus* browse cover
Broadleaf	47.1	49.8	7.2	7.4	0	0
Grass scrubland	45.6	2.6	45.6	2.6	1.8	0.1
Mahoe titoki	43.8	27.1	7.8	6.9	0	0
Bluffs & Screes	8.1	3.2	8.1	3.2	0	0
Improved grassland	58.3	1.1	58.3	1.1	0	0
Matai	57.7	46.7	16.1	25.2	1.4	0.1
Mountain Beech	40.8	59.1	16.9	27.7	68.5	16.4
Kanuka	33	43.1	30	38.2	10.1	4.6
Hall's totara	7.5	12.25	7.5	12.2	0	0
Red Beech	7.5	19.1	4.9	14	57.6	10.4
Subalpine	100	2.3	100	2.3	0	0

Table 4.18d Physical, availability, vegetative cover, and rank hunting difficulty at Isolated Hill Scenic Reserve.

Vegetation community	Mean Aspect	Mean Slope	Mean Altitude	Area of community (total ha)	Total Vegetative Cover Index	Rank Hunting difficulty
Broadleaf	283.5	26.8	467.5	780.7	71.2	6
Grass scrubland	56.9	21	943.3	84.1	47.7	2
Mahoe-titoki	31.8	22.4	268.6	66.2	60	4
Bluffs & Screes	12.2	43.4	424	363.1	23.4	11
Improved grassland	247.8	22.2	795.2	435.3	55	1
Matai	329	20.2	425.5	29.89	74.6	5
Mountain beech	287.9	22.7	415	1616.2	83.6	9
Kanuka	309.6	24	592.1	242.58	100	8
Hall's totara	215.2	27.4	844	90	44.7	7
Red beech	204.4	15.9	694.2	162.9	75.2	10
Subalpine	210.7	35	950	28.52	81.2	3

4.2.4 Models of habitat selection

4.2.4.1 Habitat correlations

Site variables from section 4.2.3 were correlated with different observation and faecal data using Spearman rank correlation (Tables 4.19a-b, 4.20a-b). Rank correlations were initially calculated for all vegetation communities (Table 4.19a-b), and were then recalculated for a subset of data that excluded subalpine vegetation (Table 4.20a-b). Significance tests as set (see methods) revealed no statistically significant relationships. For the analysis of all vegetation communitiess trends were found for post-control measures of habitat selection and Margalef's index, total broadleaf cover, broadleaf cover in the browse tier, mahoe cover in the browse tier, broadleaf cover as a proportion of total vegetative cover, and mahoe cover as a proportion of total vegetative cover (Tables 4.19a-b).

Table 4.19a Significance of Spearman rank correlations between site variables and habitat selection data for all vegetation types at Isolated Hill Scenic Reserve. [1,3] Cochrane, 1994; [2, 4] Hayward 1985. [5]Note overall use is direct observation for the entire study period.

Habitat selection	Total palatable[1]	Total palatable[2]	Browse[3]	Browse[4]	Broadleaf total cover	Broadleaf browse tier	Mahoe total cover	Mahoe browse tier	Broadleaf percentage	Mahoe percentage	Monocot cover	Vegetation area
Overall use[5]	0.883	0.491	0.148	0.581	0.169	0.496	0.119	0.396	0.209	0.396	0.375	0.979
Pre (obs)	0.716	0.904	0.284	0.313	0.090	0.436	0.085	0.319	0.205	0.319	0.778	0.914
Post (obs)	0.145	0.260	0.306	0.279	0.648	0.633	0.894	0.704	0.609	0.704	0.093	0.957
Pre (pellets)	0.853	0.247	0.120	0.894	0.357	0.806	0.274	0.839	0.422	0.839	0.259	0.555
Post (pellets)	0.779	0.296	0.836	0.104	0.036	0.002	0.067	0.025	0.002	0.025	0.873	0.544
Autumn	0.326	0.368	0.877	0.722	0.354	0.391	0.289	0.800	0.187	0.800	0.664	0.757
Winter	0.426	0.873	0.609	0.453	0.148	0.864	0.314	0.763	0.555	0.763	0.839	0.652
Spring	0.854	0.151	0.249	0.854	0.673	0.392	0.326	0.840	0.192	0.840	0.473	0.758
Summer	0.806	1.000	0.806	0.592	0.428	0.257	0.317	0.189	0.187	0.189	0.335	0.632

Table 4.19b Significance of Spearman rank correlations between site variables and habitat selection data for all vegetation types at Isolated Hill Scenic Reserve. . [5]Note overall use is direct observation for the entire study period.

Habitat selection	Total diversity	Browse diversity	Berger Parker	Margalefs	*Nothofagus* cover	*Nothofagus* browse	Hunting difficulty	Aspect	Slope	Altitude	Vegetative cover	Plot diversity
Overall use[5]	0.431	0.429	0.100	0.873	0.172	0.185	0.368	0.915	0.968	0.158	0.456	0.894
Pre (obs)	0.206	0.198	0.188	0.342	0.485	0.523	0.579	0.798	0.636	0.073	0.436	0.420
Post (obs)	0.892	0.822	0.897	0.037	0.238	0.220	0.293	0.723	0.390	0.935	0.838	0.241
Pre (pellets)	0.832	0.915	0.067	0.979	0.056	0.058	0.151	0.689	0.894	0.484	0.180	0.750
Post (pellets)	0.119	0.127	0.102	0.391	0.402	0.436	0.629	0.841	0.957	0.232	0.473	0.215
Autumn	0.757	0.709	0.073	0.951	0.223	0.190	0.817	0.130	0.597	0.301	0.172	0.631
Winter	0.761	0.726	0.273	0.481	0.388	0.425	0.954	0.717	0.965	0.134	0.227	0.695
Spring	0.758	0.853	0.080	0.975	0.193	0.166	0.062	0.473	0.598	0.643	0.361	0.688
Summer	0.881	0.875	0.301	0.306	0.595	0.558	0.651	0.764	0.055	0.612	0.602	0.682

For the analysis of the reduced data set (subalpine excluded) (Table 4.20a-b) trends were observed for the following site variables. Total palatables (as calculated from Cochrane, 1994) were correlated strongly with overall habitat selection and pre-control habitat selection. Cover of mahoe and broadleaf were correlated with post-control pellet group densities. Margalef's diversity index was correlated with post-control direct observations. Of interest *Nothofagus* cover was negatively correlated with pre-control faecal pellet densities, suggesting that feral goats were avoiding areas that had high *Nothofagus* cover.

Table 4.20a Significance of Spearman rank correlations between site variables and habitat selection data for ten vegetation types at Isolated Hill Scenic Reserve. Subalpine vegetation is not included in the analysis. [1,3] Cochrane, 1994; [2, 4] Hayward 1985. [5]Note overall use is direct observation for the entire study period.

Habitat selection	Total palatable[1]	Total palatable[2]	Browse[3]	Browse[4]	Broadleaf total cover	Broadleaf browse tier	Mahoe total cover	Mahoe browse tier	Broadleaf percentage	Mahoe percentage	Monocot cover	Vegetation area
Overall use	0.040	0.625	1.000	0.325	0.198	0.656	0.129	0.513	0.267	0.513	0.233	0.750
Pre (obs)	0.027	0.554	0.867	0.464	0.191	0.772	0.159	0.563	0.396	0.563	0.298	0.519
Post (obs)	0.440	0.420	0.221	0.369	0.890	0.449	0.985	0.598	0.425	0.598	0.104	0.641
Pre (pellets)	0.062	0.881	0.881	0.200	0.322	0.826	0.259	0.859	0.399	0.859	0.187	0.405
Post (pellets)	0.756	0.257	0.789	0.589	0.100	0.006	0.129	0.046	0.005	0.046	0.649	0.815
Autumn	0.568	0.955	0.467	0.154	0.499	0.522	0.342	0.944	0.249	0.944	0.386	0.985
Winter	0.293	0.682	0.656	0.554	0.253	0.842	0.429	0.970	0.787	0.970	0.506	0.332
Spring	0.077	0.707	0.896	0.059	0.835	0.517	0.390	0.992	0.251	0.992	0.240	0.970
Summer	0.986	0.429	0.986	0.890	0.244	0.095	0.209	0.112	0.058	0.112	0.507	0.419

Table 4.20b Spearman rank significance results for correlations between site variables and habitat selection data for ten vegetation types at Isolated Hill Scenic Reserve. Subalpine vegetation is not included in the analysis. [5]Note overall use is direct observation for the entire study period.

Habitat selection	Total diversity	Browse diversity	Berger Parker	Margalef's	*Nothofagus* cover	*Nothofagus* browse	Hunting difficulty	Aspect	Slope	Altitude	Vegetative cover	Plot diversity
Overall use	0.625	0.635	0.078	0.960	0.107	0.119	0.257	0.880	0.789	0.184	0.637	0.907
Pre (obs)	0.497	0.489	0.086	0.674	0.223	0.254	0.273	0.880	0.947	0.197	0.687	0.815
Post (obs)	0.666	0.583	0.966	0.044	0.297	0.272	0.442	0.705	0.453	0.823	0.904	0.303
Pre (pellets)	0.907	0.973	0.077	0.934	0.041	0.042	0.108	0.726	0.751	0.533	0.293	0.676
Post (pellets)	0.219	0.242	0.072	0.763	0.640	0.692	0.947	0.828	0.565	0.486	0.362	0.454
Autumn	0.480	0.429	0.072	0.664	0.144	0.116	0.622	0.128	0.408	0.443	0.283	0.364
Winter	0.929	0.972	0.225	0.735	0.243	0.278	0.817	0.735	0.845	0.227	0.393	0.986
Spring	0.970	0.858	0.082	0.679	0.120	0.098	0.023	0.422	0.851	0.851	0.544	0.410
Summer	0.603	0.607	0.351	0.484	0.754	0.705	0.615	0.783	0.108	0.338	0.783	0.931

4.2.4.2 Multiple regression models

Habitat selection data were anlaysed using multiple regression in an attempt to identify potential predictive site variables that could be used as predictors of feral goat habitat selection and use. The five models in each analysis run (2-,3-,and 4- factor regressions) with the highest coefficients of determination were recorded (the highest coefficient of determination models are presented in Table 4.21). These were used to calculate the relative importance of different site variables (Table 4.22) through the frequency of

Table 4.21 Multiple regression models accounting for habitat selection by feral goats at Isolated Hill Scenic Reserve. Models were calculated using sub-sets regression for two, three, and four factors. Presented are the three models for each temporal period, selection of models was determined by the highest r^2 values. Codes for factors are: 1 Browse (Cochrane, 1994), 2 Browse (Hayward, 1985), 3 Total palatable (Cochrane, 1994), 4 Total palatable (Hayward, 1985), 5 Broadleaf total, 6 Broadleaf browse, 7 Mahoe total, 8 Mahoe browse, 9 Broadleaf percentage, 10 Mahoe percentage, 11 Monocot cover, 12 Vegetation area, 13 Total diversity, 14 Browse diversity, 15 Berger Parker score, 16 Margalefs' score, 17 *Nothofagus* cover, 18 *Nothofagus* browse, 19 Hunting difficulty, 20 Aspect, 21 Slope, 22 Altitude, 23 Vegetative cover index, 24 Plot diversity.

Temporal scale	Factors				Coefficient of determination (r^2)
Overall use (direct observation for entire study period)	9	15	17	22	*0.96*
	15	17	22		*0.92*
	18	22			*0.73*
Pre (observation)	2	17	21	24	*0.93*
	1	3	18		*0.83*
	18	2			*0.68*
Post (observation)	6	8	14	16	*0.95*
	9	14	16		*0.91*
	13	16			*0.80*
Pre (pellets)	3	5	9	23	*0.97*
	7	15	18		*0.95*
	7	18			*0.92*
Post (pellets)	3	8	15	18	*0.95*
	5	8	20		*0.88*
	5	6			*0.82*
Autumn	2	5	10	20	*0.98*
	5	12	20		*0.93*
	5	20			*0.90*
Winter	9	12	19	22	*0.91*
	9	18	22		*0.83*
	18	22			*0.59*
Spring	2	9	13	20	*0.99*
	2	9	13		*0.97*
	2	9			*0.82*
Summer	5	8	20	24	*0.97*
	5	6	21		*0.88*
	6	21			*0.62*

occurrence of different correlates. Most temporal periods had high coefficients of determination for the four factor models (mean value 0.96), but were less well explained

using two (mean value 0.76) and three factor (mean value 0.90) models. Exceptions to this were the spring and pre-control pellet density data, which had coefficients of determination for three factor models of 0.97 and 0.95 respectively. Similarly, the pre-control pellet density data had a high coefficient of determination for the two factor models at 0.92.

Table 4.22 Importance of site variables in multiple regression models of habitat selection by feral goats at Isolated Hill Scenic Reserve. Figures are for all models percentage of models that incorporated specific site variables in the model, and for all other habitat selection data the number of models (total 15) that incorporated a particular variable. Note overall use is direct observation for the entire study period.

Eco-correlate	All models	Overall use	Pre (obs)	Post (obs)	Pre (pellets)	Post (pellets)	Autumn	Winter	Spring	Summer
Broadleaf total	26.7	12	0	10	0	0	3	1	5	5
Broadleaf percentage	25.9	0	7	0	15	4	0	1	3	5
Nothofagus browse	23.0	1	4	1	0	0	10	6	8	1
Total palatable[2]	19.3	6	0	1	11	0	3	0	5	0
Broadleaf browse	17.8	0	0	6	1	6	1	0	0	10
BergerParker	17.8	0	0	2	0	0	0	10	4	8
Margalefs'	16.3	0	2	1	1	13	4	0	1	0
Altitude	16.3	0	11	0	0	0	5	6	0	0
Mahoe total	14.8	5	1	0	1	1	2	2	7	1
Aspect	14.8	10	0	2	2	2	0	0	1	3
Nothofagus cover	14.1	0	3	0	0	0	3	8	4	1
Vegetation area	10.4	3	5	0	0	2	0	4	0	0
Mahoe browse	9.6	0	2	4	1	2	0	0	0	4
Total diversity	9.6	0	0	1	5	7	0	0	0	0
Slope	8.9	0	4	6	0	0	2	0	0	0
Plot diversity	8.2	0	1	6	1	1	2	0	0	0
Browse[3]	7.4	0	2	0	0	0	3	0	2	3
Mahoe percentage	7.4	2	1	4	1	0	0	1	0	1
Browse diversity	7.4	0	0	0	3	5	1	0	0	1
Browse[4]	6.7	1	0	1	2	1	0	0	4	0
Monocot cover	6.7	2	0	0	0	1	2	4	0	0
Total palatable[1]	5.2	1	1	0	0	0	2	2	0	1
Hunting difficulty	3.0	1	1	0	1	0	0	0	0	1
Vegetative cover	3.0	1	0	0	0	0	2	0	1	0

[1] Total cover after Cochrane (1994)
[2] Total cover after Hayward (1985)
[3] Browse tier after Cochrane (1994)
[4] Browse tier after Hayward (1985)

Broadleaf, total palatable biomass (as calculated from Hayward, 1985) and *Nothofagus* cover are the most frequent contributors to the models that were calculated. Less frequent predictors were total vegetative cover, hunting difficulty, total palatable biomass (as calculated from Cochrane, 1994), and monocotyledon cover. Of interest also was the contribution of altitude to in particular the winter model.

The nine best multiple regression models were chosen to test how well predicted values fitted observed densities of feral goats. The models were chosen on the basis of coefficient of determination, and all models were four-variable models.

Overall habitat selection (direct observation - direct observation for the entire study period.) was predicted using four variables, broadleaf as a proportion of total vegetative cover, Berger Parker Dominance index, total *Nothofagus* cover and altitude (Table 4.23). ANOVA analysis of the model reveals a statistically highly significant result ($F_{4,6} = 34.6$, $P<0.001$). Figure 4.15 reveals that generally the predicted values tend to underestimate actual habitat selection.

Table 4.23 Four factor multiple regression for overall habitat selection (direct observation) by feral goats at Isolated Hill Scenic Reserve ($r^2 = 0.96$).

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2Tail)
CONSTANT	0.354	0.03	0	.	11.643	0.000
BROADLPROP	-0.008	0.004	-0.237	0.62	-2.241	0.066
BP	-0.252	0.044	-0.499	0.895	-5.673	0.001
NOTTOT	-0.002	0	-0.656	0.903	-7.486	0.000
ALT	-2.1×10^{-4}	0	-0.668	0.637	-6.406	0.001

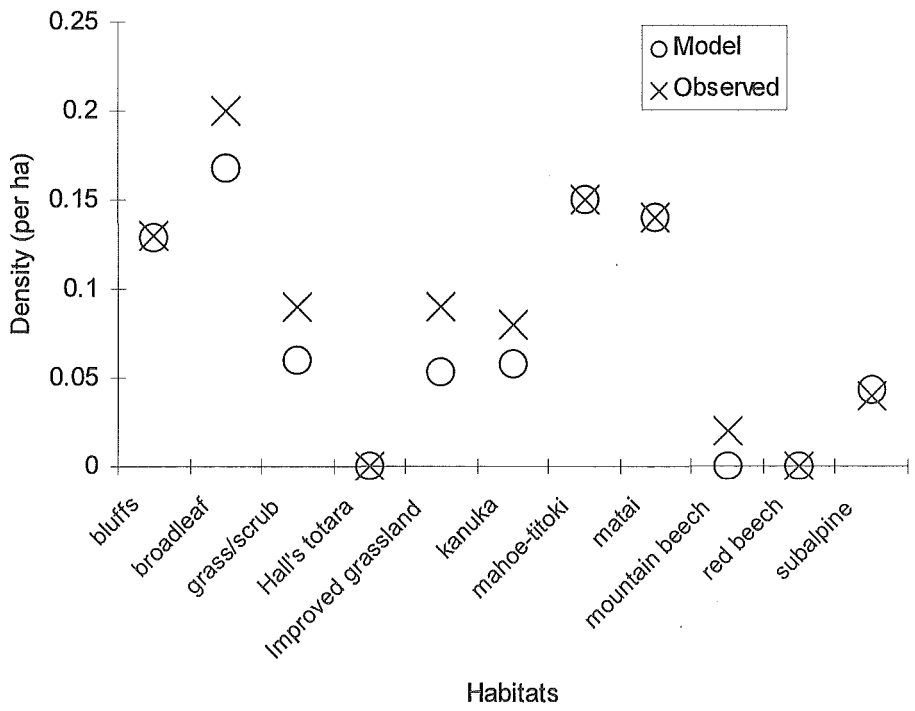


Figure 4.15 Predicted and observed values for overall habitat selection (direct observation data) for feral goats at Isolated Hill Scenic Reserve. The predicted values were from a four variable model.

Habitat selection by feral goats prior to the cull treatment was modelled using the following variables, palatable species in the browse tier (calculated from Hayward 1985), total *Nothofagus* cover, slope for each of the vegetation types, and the mean number of species per vegetation quadrat (as a measure of diversity) (Table 4.24) (ANOVA $F_{4,6} = 19.72$, $P = 0.001$). Again the predicted values tended to underestimate actual habitat selection (Fig. 4.16).

Table 4.24 Four factor multiple regression for pre-control treatment habitat selection (direct observation) by feral goats at Isolated Hill Scenic Reserve ($r^2 = 0.93$).

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2Tail)
CONSTANT	-0.627	0.109	0	.	-5.751	0.001
BROHAY	-0.008	0.001	-1.014	0.337	-5.425	0.002
NOTTOT	-0.002	0	-0.487	0.74	-3.857	0.008
SLOPE	0.013	0.002	1.058	0.301	5.343	0.002
SPPPLOT	0.036	0.005	2.069	0.168	7.806	0.000

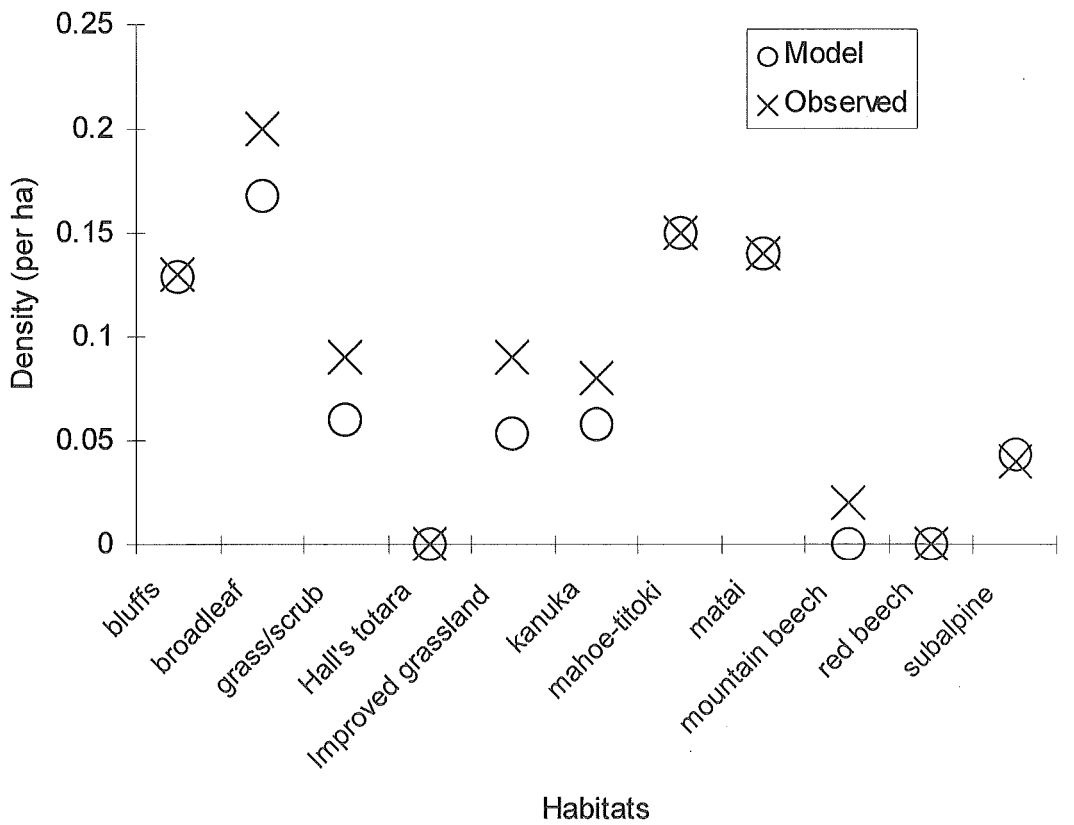


Figure 4.16 Predicted and observed values for pre-control treatment habitat selection (direct observation data) for feral goats at Isolated Hill Scenic Reserve. The predicted values were from a four variable model.

The multiple regression model of habitat selection after the cull-treatment utilised three variables that were centred upon the browse tier. Broadleaf and mahoe cover in the browse tier were used (although in opposite directions, as indicated by the coefficients) as was browse tier diversity (Table 4.25). Margalef's index of evenness was also utilised in the model. ANOVA analysis was significant ($F_{4,6} = 28.78$, $P < 0.001$). Two habitats were poorly predicted by the model; bluffs and screes (which the model under-predicted), and grass/scrubland (which the model over-predicted). The bluffs and screes community has low values for all of the browse variables, thus feral goat habitat selection for this community is probably in response to other variables. In the case of grass/scrubland vegetation its high browse tier diversity would account for the over-prediction by the model.

Table 4.25 Four factor multiple regression for post-control treatment habitat selection (direct observation) by feral goats at Isolated Hill Scenic Reserve ($r^2 = 0.95$).

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2Tail)
CONSTANT	0.336	0.045	0	.	7.491	0.000
BROADLBROW	0.148	0.029	0.762	0.366	5.072	0.002
MAHBROW	-0.249	0.083	-0.528	0.265	-2.993	0.024
BROWDIV	0.008	0.001	1.024	0.229	5.397	0.002
MARG	-0.183	0.024	-1.158	0.362	-7.661	0.000

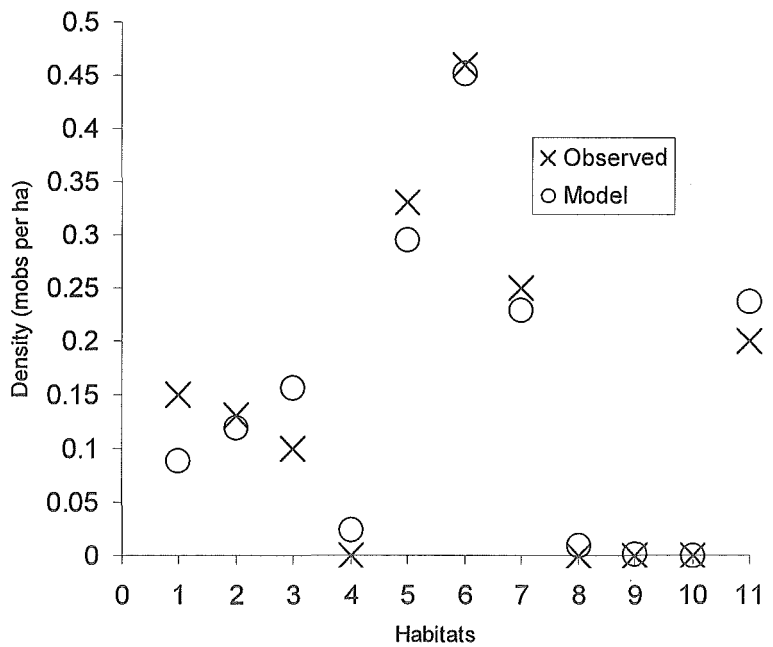


Figure 4.17 Predicted and observed values for post-control treatment habitat selection (direct observation data) for feral goats at Isolated Hill Scenic Reserve. The predicted values were from a four variable model. Habitat codes are 1, bluffs and screes; 2, broadleaf; 3, grass/scrubland; 4, Hall's totara; 5, improved grassland; 6, kanuka; 7, mahoe-titoki; 8, matai; 9, mountain beech; 10, red beech; 11, subalpine.

The habitat selection model for autumn use (direct observation) (Table 4.26) revealed good prediction of bluffs and screes, grass scrubland, Hall's totara, kanuka, matai, mountain beech and red beech habitats, underestimation of feral goat density in broadleaf and mahoe-titoki habitats and overestimation of density in improved grassland and subalpine habitats (Fig. 4.18). The underestimation of broadleaf and mahoe-titoki habitats again suggests that feral goats are responding to variables other than browse within these habitats. ANOVA analysis was significant ($F_{4,6} = 66.203$, $P < 0.001$).

Table 4.26 Four factor multiple regression for autumn habitat selection (direct observation) by feral goats at Isolated Hill Scenic Reserve ($r^2 = 0.98$).

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2Tail)
CONSTANT	0.092	0.009	0	.	10.098	0.000
BROHAY	-0.004	0.001	-0.602	0.224	-4.691	0.003
BROADLTOT	0.010	0.001	0.823	0.577	10.29	0.000
MAHPROP	0.081	0.022	0.455	0.244	3.701	0.010
ASPECT	-2.51×10^{-4}	0	-0.503	0.496	-5.835	0.001

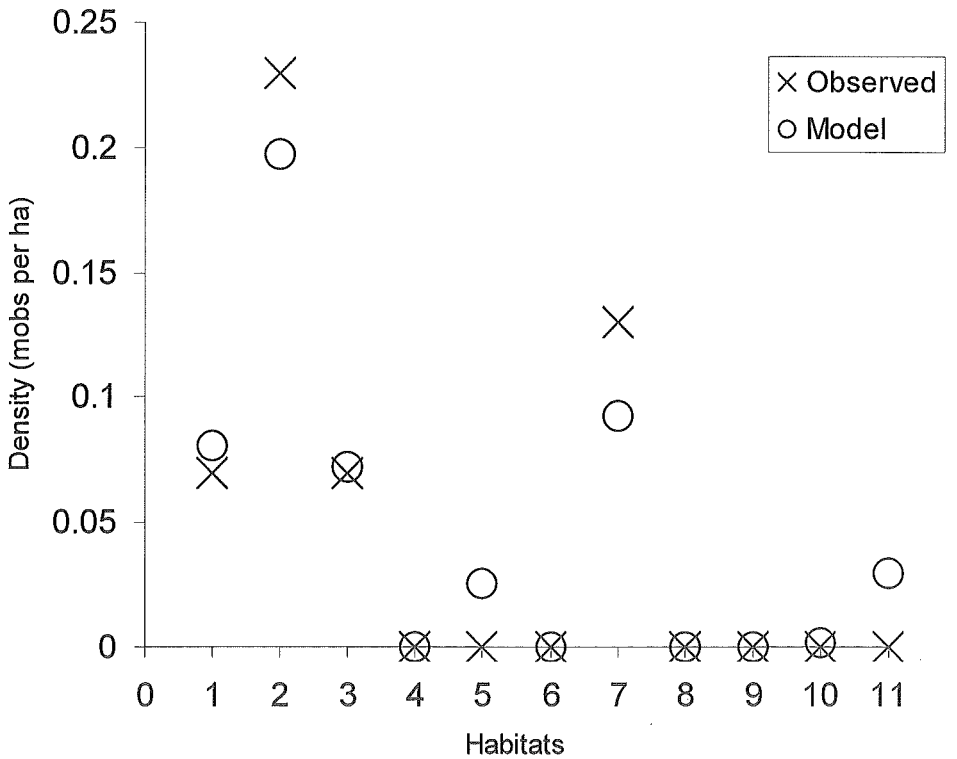


Figure 4.18 Predicted and observed values for autumn habitat selection (direct observation data) for feral goats at Isolated Hill Scenic Reserve. The predicted values were from a four variable model. Habitat codes are 1, bluffs and screes; 2, broadleaf; 3, grass/scrubland; 4, Hall's totara; 5, improved grassland; 6, kanuka; 7, mahoe-titoki; 8, matai; 9, mountain beech; 10, red beech; 11, subalpine.

The multiple regression model of winter habitat selection utilised broadleaf as a proportion of total vegetative cover, area of vegetation types within the study area, the rank difficulty of hunting, and altitude (Table 4.27). Of were the negative weightings for hunting difficulty and altitude. Habitats that were weighted as difficult to hunt include bluffs and screes, mountain beech, kanuka, and red beech vegetation types. All tend to hold water, hence during the wetter, colder, period of winter such habitats are avoided. Similarly the negative altitude weighting means that higher altitude habitats tend to be avoided during this period. These two trends can be observed in the observed and predicted density values (Fig. 4.19). ANOVA analysis was again significant ($F_{4,6} = 16.072$, $P < 0.01$).

Table 4.27 Four factor multiple regression for winter habitat selection (direct observation) by feral goats at Isolated Hill Scenic Reserve ($r^2 = 0.92$).

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2Tail)
CONSTANT	1.107	0.142	0	.	7.797	0.000
BROADLPROP	-0.087	0.016	-0.932	0.478	-5.406	0.002
AREA	5.51×10^{-4}	0	-0.684	0.729	-4.9	0.003
HUNTRANK	-0.020	0.008	-0.380	0.641	-2.551	0.043
ALT	-0.001	0	-1.512	0.370	-7.706	0.000

The spring habitat selection model incorporated palatable species in the browse tier (calculated from Hayward 1985), broadleaf as a proportion of total vegetative cover, total diversity of individual habitats, and aspect of habitats (Table 4.28). In the four habitats in which feral goats were recorded the predicted values slightly underestimated actual observed densities (Fig. 4.20), except broadleaf in which the predicted number of mobs per ha was 0.05 less. ANOVA analysis of the regression model yielded a significant result ($F_{4,6} = 105.559$, $P<0.001$).

Table 4.28 Four factor multiple regression for spring habitat selection (direct observation) by feral goats at Isolated Hill Scenic Reserve ($r^2 = 0.99$).

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2Tail)
CONSTANT	-0.026	0.017	0	.	-1.513	0.181
BROHAY	-0.011	0.001	-1.034	0.39	-13.363	0.000
BROADLPROP	0.057	0.004	0.815	0.626	13.349	0.000
TOTDIV	0.003	0	0.494	0.42	6.631	0.001
ASPECT	1.0×10^{-4}	0	0.223	0.407	2.939	0.026

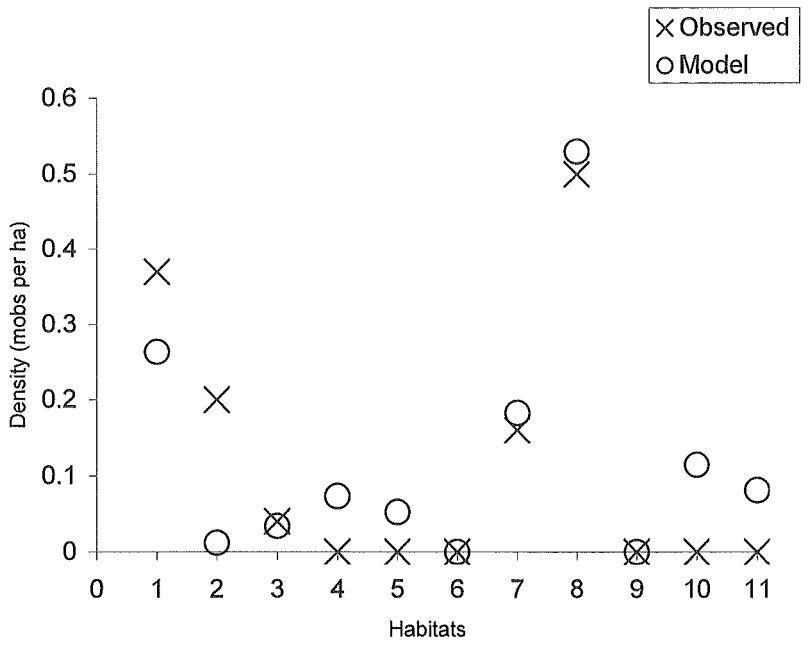


Figure 4.19 Predicted and observed values for winter habitat selection (direct observation data) for feral goats at Isolated Hill Scenic Reserve. The predicted values were from a four variable model. Habitat codes are 1, bluffs and screes; 2, broadleaf; 3, grass/scrubland; 4, Hall's totara; 5, improved grassland; 6, kanuka; 7, mahoe-titoki; 8, matai; 9, mountain beech; 10, red beech; 11, subalpine.

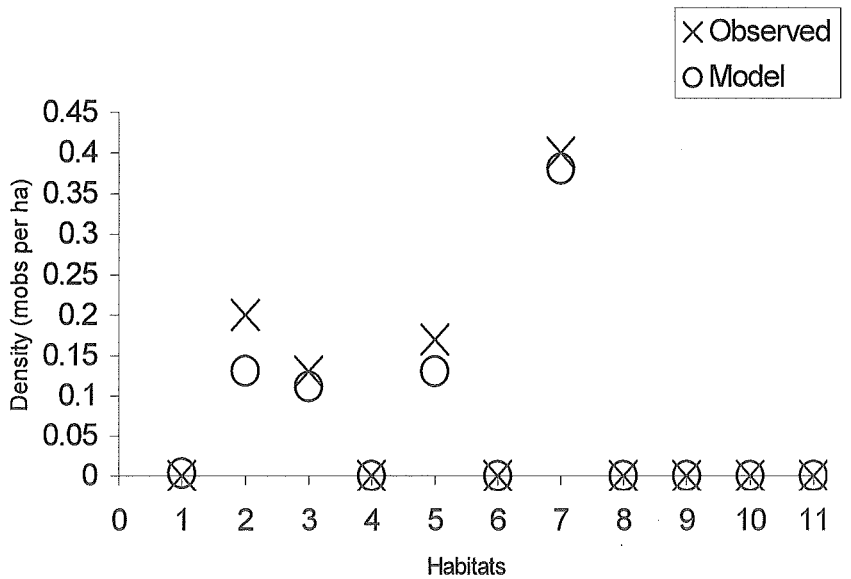


Figure 4.20 Predicted and observed values for spring habitat selection (direct observation data) for feral goats at Isolated Hill Scenic Reserve. The predicted values were from a four variable model. Habitat codes are 1, bluffs and screes; 2, broadleaf; 3, grass/scrubland; 4, Hall's totara; 5, improved grassland; 6, kanuka; 7, mahoe-titoki; 8, matai; 9, mountain beech; 10, red beech; 11, subalpine.

Summer habitat selection utilised total broadleaf cover, mahoe cover in the browse tier, habitat aspect, and species diversity in vegetation quadrats in the four variable multiple regression model (Table 4.29) (ANOVA $F_{4,6} = 46.249$, $P<0.001$). A wide range of habitats were utilised during summer and while the predicted values were close to observed feral goat densities for most habitats, broadleaf habitat selection in particular was poorly predicted (Fig. 4.21) (despite total broadleaf cover being incorporated in the regression model).

Table 4.29 Four factor multiple regression for summer habitat selection (direct observation) by feral goats at Isolated Hill Scenic Reserve ($r^2 = 0.97$).

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2Tail)
CONSTANT	0.18	0.016	0	.	11.008	0.000
BROADLTOT	0.009	0.001	0.818	0.75	9.794	0.000
MAHBROW	0.184	0.019	0.826	0.694	9.505	0.000
ASPECT	-1.0×10^{-4}	0	-0.45	0.618	-4.889	0.003
SPPPLOT	-0.009	0.001	-0.635	0.6	-6.796	0.000

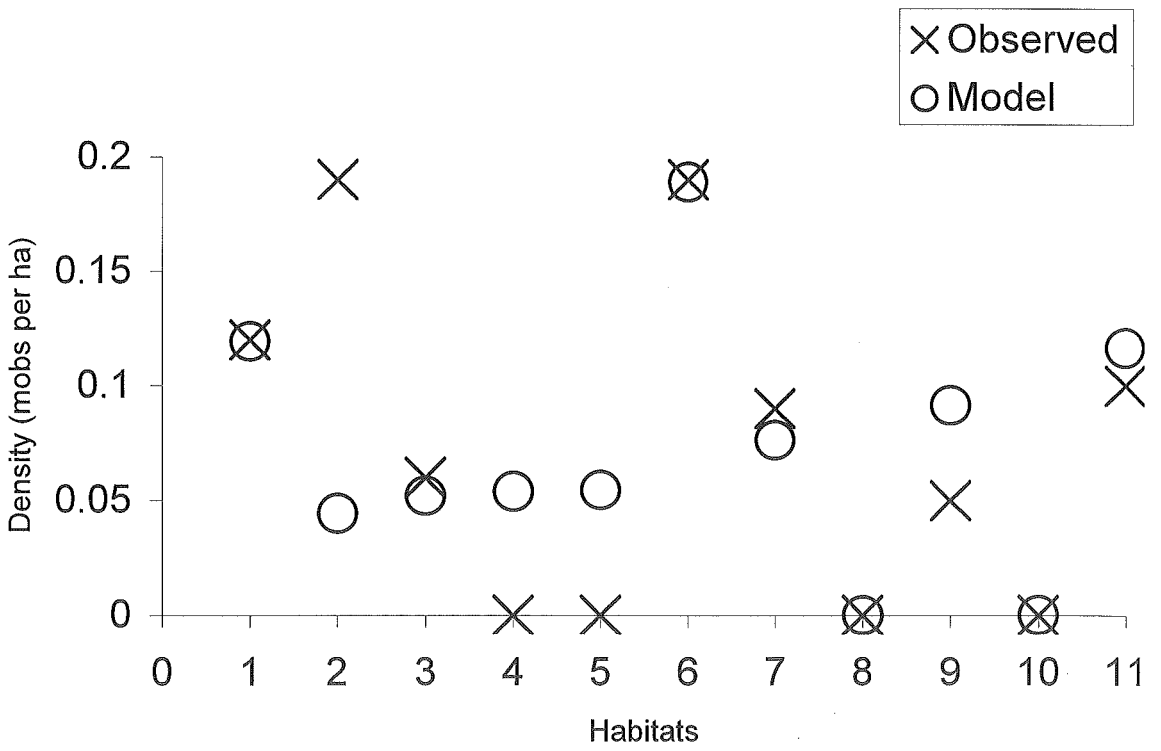


Figure 4.21 Predicted and observed values for summer habitat selection (direct observation data) for feral goats at Isolated Hill Scenic Reserve. The predicted values were from a four variable model. Habitat codes are 1, bluffs and screes; 2, broadleaf; 3, grass/scrubland; 4, Hall's totara; 5, improved grassland; 6, kanuka; 7, mahoe-titoki; 8, matai; 9, mountain beech; 10, red beech; 11, subalpine.

Multiple regression models were also calculated for pre-control and post-control pellet density data. The pre-control model utilised three variables only as four factor models generally had multi-collinearity problems (for example the incorporation of total mahoe cover, and mahoe cover in the browse tier) ($F_{3,7} = 42.79$, $P < 0.001$). The site variables used were total mahoe cover, Berger Parker index, and *Nothofagus* cover in the browse tier (Table 4.30). Comparison between predicted and observed pellet groups per ha reveals that generally the predicted values underestimate the value for each habitat (except in the cases of improved grassland and subalpine habitats) (Fig. 4.22). Prediction is particularly underestimated for broadleaf habitat.

Table 4.30 Three factor multiple regression for pre-control treatment habitat selection (faecal observation) by feral goats at Isolated Hill Scenic Reserve ($r^2 = 0.95$).

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2Tail)
CONSTANT	1148.329	217.122	0	.	5.289	0.001
MAHTOT	50.194	7.494	0.677	0.723	6.698	0.000
BP	-828.268	401.547	-0.204	0.754	-2.063	0.078
NOTBROW	-68.583	8.688	-0.719	0.891	-7.894	0.000

The post-control model was a four variable model that used palatable cover in the browse tier (as calculated from Cochrane, 1994), mahoe cover in the browse tier, Berger Parker index score and *Nothofagus* cover in the browse tier (Table 4.31). ANOVA analysis was significant ($F_{4,6} = 31.451$, $P < 0.001$), and actual values were well fitted by predicted values (Fig. 4.25). Improved grassland and grass/scrubland had the greatest differences between predicted and actual values. In the case of improved grassland feral goats (despite high monocotyledon cover) are responding to other variables, for example presence of domestic stock.

Table 4.31 Four factor multiple regression for post-control treatment habitat selection (pellet group density) by feral goats at Isolated Hill Scenic Reserve ($r^2 = 0.95$).

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2Tail)
CONSTANT	652.363	69.974	0	.	9.323	0.000
TOTBHCC	-2.328	0.541	-0.445	0.71	-4.3	0.005
MAHBROW	404.559	44.087	0.916	0.761	9.176	0.000
BP	-674.740	110.649	-0.613	0.751	-6.098	0.001
NOTBROW	-10.217	2.665	-0.395	0.716	-3.834	0.009

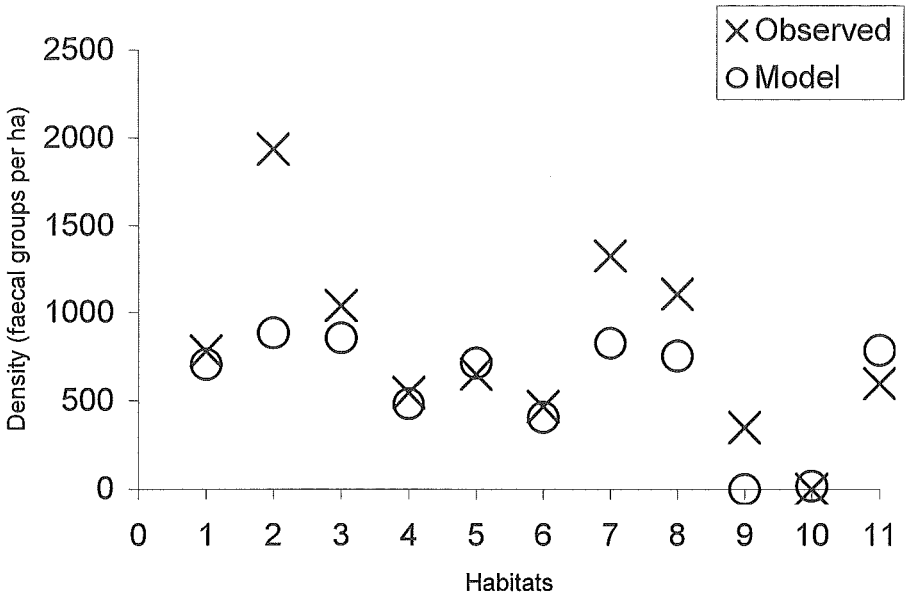


Figure 4.22 Predicted and observed values for pre-control treatment habitat selection (pellet group densities) for feral goats at Isolated Hill Scenic Reserve. The predicted values were from a three variable model. Habitat codes are 1, bluffs and screes; 2, broadleaf; 3, grass/scrubland; 4, Hall's totara; 5, improved grassland; 6, kanuka; 7, mahoe-titoki; 8, matai; 9, mountain beech; 10, red beech; 11, subalpine.

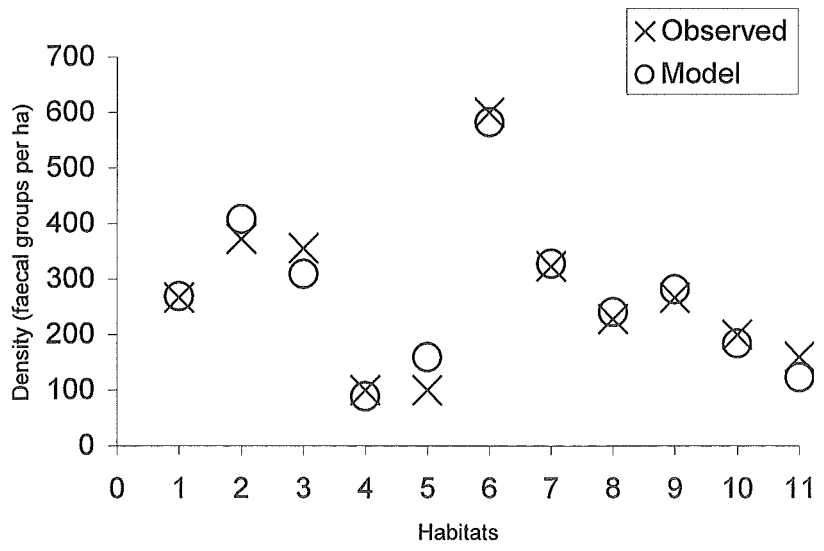


Figure 4.26 Predicted and observed values for post-control treatment habitat selection (pellet group density) for feral goats at Isolated Hill Scenic Reserve. The predicted values were from a four variable model. Habitat codes are 1, bluffs and screes; 2, broadleaf; 3, grass/scrubland; 4, Hall's totara; 5, improved grassland; 6, kanuka; 7, mahoe-titoki; 8, matai; 9, mountain beech; 10, red beech; 11, subalpine.

4.2.5 Habitat suitability index – Novellie and Winkler model

Predictive utilisation indices were calculated for each of the eleven different communities identified for Isolated Hill Scenic Reserve. Three different types of index were calculated:

1. a community HSI which used preference ratings and percentage cover calculated for individual species in each separate community (Table 4.32a-d);
2. a landscape HSI in which preference ratings were calculated using the percentage cover of a species for the whole reserve, and then weighted by the cover within specific communites (Table 4.33);
3. and a diet contribution in which percentage contribution to diet rather than preference was weighted by the cover of species in individual communities (Table 4.34).

Table 4.32a Calculated predictive utilisation numbers for Red beech, Mountain beech, and Kanuka communities at Isolated Hill Scenic Reserve. Mean value, upper value and lower value (95% Confidence intervals) are presented. Values are calculated from transformed Ivlev's electivity indices for each food type in each community (see text for full description).

Food types	Red Beech (mean)	Red Beech (upper)	Red Beech (lower)	Mtn Beech (mean)	Mtn Beech (upper)	Mtn Beech (lower)	Kanuka (mean)	Kanuka (upper)	Kanuka (lower)
Griselinia littoralis	1.11	1.11	1.1	0.58	0.58	0.57	6.27	6.42	6.06
Monocot spp.	0.14	0.14	0.14	1.35	1.38	1.31	4.64	4.90	4.20
Melicytus ramiflorus	0	0	0	6.85	8.10	5.02	1.54	1.59	1.42
Coprosma rhamnoides	0	0	0	3.03	4.36	1.20	3.15	4.61	1.21
Clematis spp.	0.01	0.01	0	0.06	0.06	0	0.63	0.72	0
Prumnopitys taxifolia	0.29	0.32	0	1.78	3.80	0	0	0	0
Coriaria arborea	0	0	0	0	0	0	0.67	0.90	0
Sophora microphylla	0.03	0.03	0.03	0.04	0.04	0.04	0.44	0.50	0.21
Cirsium spp.	0	0	0	0.01	0.01	0	0.2	0.22	0
Senecio monroi	0	0	0	0.04	0.04	0	0	0	0
Coprosma propinqua	0.13	0.14	0.04	0.11	0.12	0.04	0.55	0.78	0.06
Carpodetus serratus	0.67	1.21	0	0.67	1.19	0	0.47	0.67	0
Asplenium spp.	0.01	0.01	0.01	0.07	0.08	0.04	0.33	0.43	0.06
Pseudopanax crassifolium	0.46	0.84	0	0.21	0.26	0	0.38	0.60	0
Cordyline australis	0	0	0	0.18	0.24	0	0.36	0.65	0
Pimelea spp.	0	0	0	0	0	0	0	0	0
Pennantia corymbosa	0	0	0	0.24	0.45	0	0.19	0.30	0
Myrsine australis	0.28	0.69	0	0.29	0.79	0	0.19	0.33	0
Macropiper excelsum	0	0	0	0	0	0	0	0	0
Coprosma spp.	0.23	0.59	0	0.23	0.59	0	0.24	0.64	0
Pittosporum tenuifolium	0	0	0	0.06	0.07	0.03	0.13	0.19	0.04
Myoporum laetum	0	0	0	0	0	0	0	0	0
Phymatosorus diversifolius	0	0	0	0.02	0.02	0	0.15	0.38	0
Pittosporum eugenioides	0.03	0.03	0	0.03	0.04	0	0	0	0
Rubus spp.	0.01	0.01	0	0.03	0.04	0	0.06	0.08	0
Pseudopanax arboreus	0.05	0.06	0	0.03	0.04	0	0.09	0.2	0
Nothofagus fusca	0.02	0.06	0	0.02	0.05	0	0	0	0
N. solandri	0.02	0.06	0	0.02	0.06	0	0.02	0.06	0
Blechnum spp.	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	**3.5**	**5.32**	**1.33**	**15.96**	**22.42**	**8.26**	**20.71**	**25.18**	**13.27**

Table 4.32b Calculated predictive utilisation numbers for Matai, Broadleaf, and Mahoe-titoki communities at Isolated Hill Scenic Reserve. Average value, high value and low value (95% Confidence intervals) are presented. Values are calculated from transformed Ivlev's electivity indices for each food type in each community (see text for full description).

Food types	Matai (mean)	Matai (upper)	Matai (lower)	Broadleaf (mean)	Broadleaf (upper)	Broadleaf (lower)	Mahoe -titoki (mean)	Mahoe -titoki (upper)	Mahoe -titoki (lower)
Griselinia littoralis	7.18	7.38	6.90	13.71	14.47	12.73	3.31	3.35	3.25
Monocot spp.	3.26	3.39	3.04	2.69	2.77	2.53	1.20	1.22	1.17
Melicytus ramiflorus	4.76	5.34	3.80	7.46	8.98	5.34	6.63	7.79	4.90
Coprosma rhamnoides	1.46	1.71	0.84	0.12	0.12	0.11	0.09	0.09	0.08
Clematis spp.	0.08	0.08	0	0.37	0.40	0	0	0	0
Prumnopitys taxifolia	2.02	5.08	0	0	0	0	1.98	4.85	0
Coriaria arborea	0	0	0	0	0	0	0	0	0
Sophora microphylla	1.45	2.34	0.32	0.17	0.18	0.12	0.04	0.04	0.04
Cirsium spp.	0.02	0.02	0	0.12	0.12	0	0	0	0
Senecio monroi	0.26	0.30	0	0.75	1.20	0	0	0	0
Coprosma propinqua	0.4	0.5	0.06	0.75	1.26	0.06	0.18	0.2	0.05
Carpodetus serratus	0.57	0.91	0	0.3	0.38	0	0.39	0.53	0
Asplenium spp.	0	0	0	0	0	0	0.11	0.12	0.05
Pseudopanax crassifolium	0.30	0.43	0	0	0	0	0.08	0.08	0
Cordyline australis	0	0	0	0.31	0.5	0	0.04	0.04	0
Pimelea spp.	0	0	0	0	0	0	0	0	0
Pennantia corymbosa	0.08	0.09	0	0.05	0.06	0	0.22	0.38	0
Myrsine australis	0.28	0.68	0	0.29	0.76	0	0.29	0.77	0
Macropiper excelsum	0	0	0	0	0	0	0.14	0.22	0
Coprosma spp.	0.23	0.62	0	0.11	0.15	0	0.19	0.38	0
Pittosporum tenuifolium	0.12	0.18	0.04	0.12	0.18	0.04	0.04	0.04	0.02
Myoporum laetum	0.16	0.41	0	0.17	0.49	0	0.16	0.42	0
Phymatosorus diversifolius	0.05	0.06	0	0	0	0	0.06	0.08	0
Pittosporum eugenioides	0.03	0.03	0	0	0	0	0.04	0.04	0
Rubus spp.	0.02	0.03	0	0.07	0.11	0	0.15	0.42	0
Pseudopanax arboreus	0.09	0.20	0	0	0	0	0	0	0
Nothofagus fusca	0	0	0	0	0	0	0	0	0
N. solandri	0.02	0.06	0	0	0	0	0	0	0
Blechnum spp.	0.01	0.01	0.01	0	0	0	0	0	0
Total	**22.85**	**29.85**	**15.01**	**27.56**	**32.13**	**20.93**	**15.34**	**21.06**	**9.56**

Table 4.32c Calculated predictive utilisation numbers for Pasture, Subalpine and Grass/scrubland communities at Isolated Hill Scenic Reserve. Average value, high value and low value (95% Confidence intervals) are presented. Values are calculated from transformed Ivlev's electivity indices for each food type in each community (see text for full description).

Food types	Pasture (mean)	Pasture (upper)	Pasture (lower)	Subalpine (mean)	Subalpine (upper)	Subalpine (lower)	Grass /scrub (mean)	Grass /scrub (upper)	Grass /scrub (lower)
Griselinia littoralis	0	0	0	0	0	0	0	0	0
Monocot spp.	15.07	18.27	11.29	17.04	21.25	12.36	13.96	16.67	10.65
Melicytus ramiflorus	0	0	0	0	0	0	0	0	0
Coprosma rhamnoides	0.02	0.02	0.02	0	0	0	0	0	0
Clematis spp.	0.02	0.02	0	0	0	0	0	0	0
Prumnopitys taxifolia	0	0	0	0	0	0	0	0	0
Coriaria arborea	0	0	0	0	0	0	0	0	0
Sophora microphylla	0	0	0	0	0	0	0	0	0
Cirsium spp.	0.02	0.02	0	0	0	0	0.04	0.04	0
Senecio monroi	0	0	0	0	0	0	0	0	0
Coprosma propinqua	0.36	0.45	0.05	0.57	0.81	0.06	0.08	0.08	0.03
Carpodetus serratus	0	0	0	0	0	0	0	0	0
Asplenium spp.	0	0	0	0	0	0	0	0	0
Pseudopanax crassifolium	0	0	0	0	0	0	0	0	0
Cordyline australis	0	0	0	0	0	0	0	0	0
Pimelea spp.	0.08	0.09	0	0	0	0	0.04	0.04	0
Pennantia corymbosa	0	0	0	0	0	0	0	0	0
Myrsine australis	0	0	0	0	0	0	0	0	0
Macropiper excelsum	0	0	0	0	0	0	0	0	0
Coprosma spp.	0	0	0	0	0	0	0.13	0.2	0
Pittosporum tenuifolium	0	0	0	0	0	0	0	0	0
Myoporum laetum	0	0	0	0	0	0	0	0	0
Phymatosorus diversifolius	0	0	0	0	0	0	0	0	0
Pittosporum eugenioides	0	0	0	0	0	0	0	0	0
Rubus spp.	0	0	0	0	0	0	0	0	0
Pseudopanax arboreus	0	0	0	0	0	0	0	0	0
Nothofagus fusca	0	0	0	0	0	0	0	0	0
N. solandri	0	0	0	0	0	0	0.02	0.05	0
Blechnum spp.	0.01	0.01	0.01	0	0	0	0.01	0.01	0.01
Total	**15.58**	**18.88**	**11.37**	**17.61**	**22.06**	**12.42**	**14.28**	**17.09**	**10.69**

Table 4.32d Calculated predictive utilisation numbers for Hall's totara and Bluffs and screes communities at Isolated Hill Scenic Reserve. Mean value, high value and low value (95% Confidence intervals) are presented. Values are calculated from transformed Ivlev's electivity indices for each food type in each community (see text for full description).

Food types	Hall's totara (mean)	Hall's totara (upper)	Hall's totara (lower)	Bluffs and screes (mean)	Bluffs and screes (upper)	Bluffs and screes (lower)
Griselinia littoralis	0.49	0.49	0.49	0.08	0.08	0.08
Monocot spp.	3.35	3.48	3.12	5.76	6.18	5.11
Melicytus ramiflorus	0	0	0	0	0	0
Coprosma rhamnoides	1.33	1.54	0.8	0.16	0.16	0.15
Clematis spp.	0.42	0.46	0	0	0	0
Prumnopitys taxifolia	0	0	0	0	0	0
Coriaria arborea	0	0	0	0	0	0
Sophora microphylla	0.39	0.43	0.20	0	0	0
Cirsium spp.	0	0	0	0	0	0
Senecio monroi	0	0	0	0.14	0.16	0
Coprosma propinqua	0.60	0.88	0.06	0.30	0.36	0.05
Carpodetus serratus	0.56	0.89	0	0	0	0
Asplenium spp.	0.29	0.36	0.06	0	0	0
Pseudopanax crassifolium	0.27	0.37	0	0	0	0
Cordyline australis	0	0	0	0	0	0
Pimelea spp.	0	0	0	0	0	0
Pennantia corymbosa	0.24	0.43	0	0	0	0
Myrsine australis	0.19	0.33	0	0	0	0
Macropiper excelsum	0	0	0	0	0	0
Coprosma spp.	0.19	0.40	0	0.08	0.10	0
Pittosporum tenuifolium	0.13	0.19	0.04	0	0	0
Myoporum laetum	0	0	0	0	0	0
Phymatosorus diversifolius	0	0	0	0	0	0
Pittosporum eugenioides	0.12	0.21	0	0	0	0
Rubus spp.	0.12	0.24	0	0	0	0
Pseudopanax arboreus	0	0	0	0	0	0
Nothofagus fusca	0	0	0	0	0	0
N. solandri	0	0	0	0	0	0
Blechnum spp.	0.01	0.01	0.01	0	0	0
Total	**8.7**	**10.71**	**4.78**	**6.52**	**7.04**	**5.39**

Contributions to overall community HSI (Table 4.32a-d) score were greatest for *Griselinia littoralis*, monocotyledon species, and *Melicytus ramiflorus*. Species that did not contribute to large proportions of the community HSI scores were *Blechnum* spp., *Myoporum laetum*, *Nothofagus fusca, N. solandri, Phymatosorus diversifolius, Pimelea* spp., *Pittosporum eugenioides, P. tenuifolium, Pseudopanax arboreus*, and *Rubus* spp. The order of HSI values for individual communities is shown in Figure 4.27. Broadleaf and matai communities have the highest values, with red beech ranked lowest. Of interest though is the mid ranking of mountain beech, a community that is perceived to have low value to feral goats, yet clearly has a large resource of preferred food items within it.

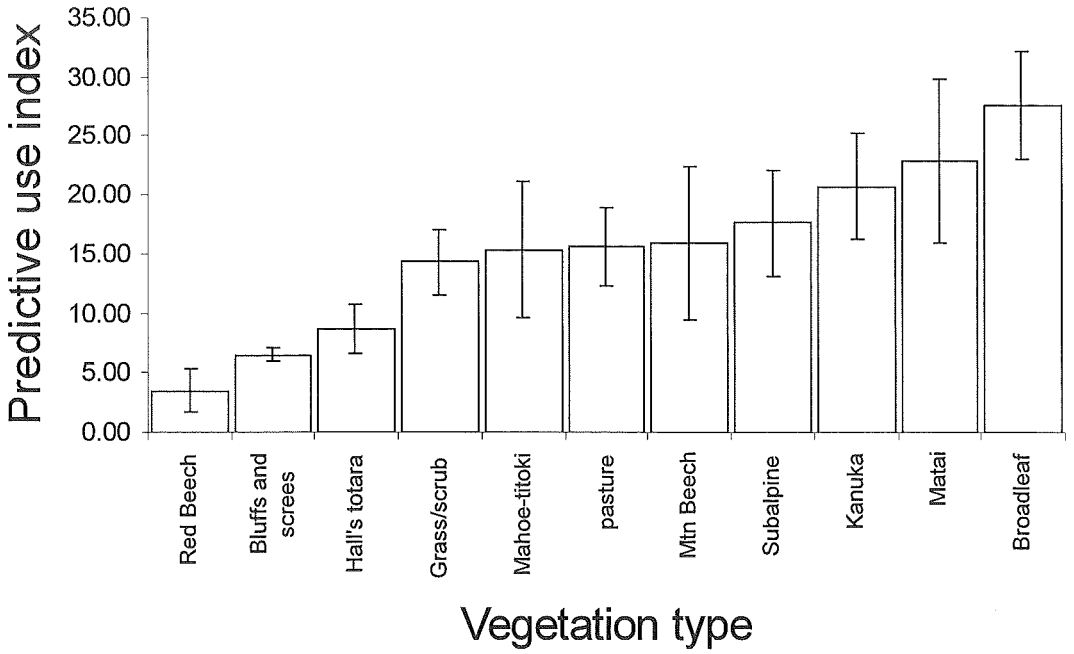


Figure 4.27 Predictive habitat utilisation at the community scale. Mean value, (± 95% Confidence intervals) are presented. Values are calculated from transformed Ivlev's electivity indices for each food type in each community.

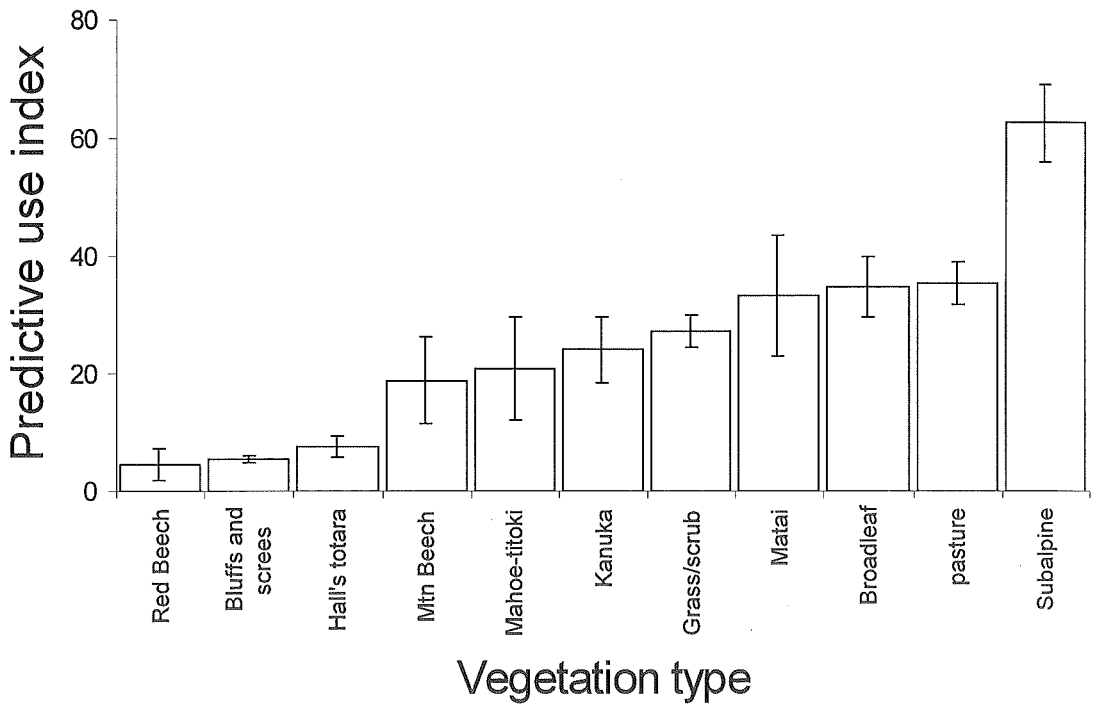


Figure 4.28 Predictive habitat utilisation at the landscape scale. Mean value, (± 95% Confidence intervals) are presented.

Table 4.33 Landscape model of predictive habitat utilisation. In the landscape model the prefernce for the food type (calculated for the whole of Isolated Hill Scenic Reserve) is weighted by its percentage cover in individual communities.

Food types	Percentage Cover in reserve	Preference	Red Beech	Mtn Beech	Hall's totara	Matai	Broadleaf	Mahoe-titoki	Kanuka	Bluffs and screes	Subalpine	Grass/scrub	pasture
Griselinia littoralis	5.02	0.89	1.02	0.52	0.45	7.75	18.35	3.21	6.59	0.07	0.00	0.00	0.00
Monocot spp.	10.48	0.66	0.09	0.96	2.65	2.56	2.05	0.85	3.97	5.30	66.22	28.87	37.49
Melicytus ramiflorus	10.14	0.56	0.00	8.24	0.00	4.23	10.03	7.69	0.97	0.00	0.00	0.00	0.00
Coprosma rhamnoides	6.36	0.38	0.00	4.92	0.77	0.89	0.05	0.03	5.84	0.06	0.00	0.00	0.01
Clematis spp.	0.18	0.93	0.01	0.05	0.47	0.07	0.41	0.00	0.78	0.00	0.00	0.00	0.02
Prumnopitys taxifolia	4.44	0.33	0.11	3.11	0.00	8.18	0.00	6.66	0.00	0.00	0.00	0.00	0.00
Coriaria arborea	0.07	0.96	0.00	0.00	0.00	0.00	0.00	0.00	1.06	0.00	0.00	0.00	0.00
Sophora microphylla	0.18	0.90	0.03	0.04	0.45	8.78	0.17	0.04	0.54	0.00	0.00	0.00	0.00
Cirsium spp.	0.05	0.97	0.00	0.01	0.00	0.02	0.12	0.00	0.22	0.00	0.00	0.04	0.02
Senecio monroi	0.50	0.69	0.00	0.03	0.00	0.24	1.59	0.00	0.00	0.12	0.00	0.00	0.00
Coprosma propinqua	1.20	0.43	0.06	0.05	0.76	0.30	1.90	0.10	0.60	0.19	0.65	0.04	0.26
Carpodetus serratus	2.41	0.24	1.22	1.15	0.49	0.52	0.12	0.19	0.29	0.00	0.00	0.00	0.00
Asplenium spp.	0.09	0.88	0.01	0.07	0.44	0.00	0.00	0.12	0.57	0.00	0.00	0.00	0.00
Pseudopanax crassifolium	0.30	0.66	1.35	0.21	0.33	0.40	0.00	0.06	0.69	0.00	0.00	0.00	0.00
Cordyline australis	0.37	0.58	0.00	0.17	0.00	0.00	0.47	0.03	0.77	0.00	0.00	0.00	0.00
Pimelea spp.	0.01	0.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.10
Pennantia corymbosa	0.55	0.36	0.00	0.41	0.36	0.04	0.02	0.28	0.18	0.00	0.00	0.00	0.00
Myrsine australis	3.35	0.08	0.23	0.46	0.04	0.21	0.36	0.37	0.04	0.00	0.00	0.00	0.00
Macropiper excelsum	0.01	0.98	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00
Coprosma spp.	3.74	0.06	0.34	0.33	0.06	0.65	0.01	0.06	1.04	0.01	0.00	0.02	0.00
Pittosporum tenuifolium	0.17	0.50	0.00	0.04	0.25	0.21	0.22	0.02	0.25	0.00	0.00	0.00	0.00
Myoporum laetum	2.54	0.06	0.00	0.00	0.00	0.13	0.78	0.14	0.00	0.00	0.00	0.00	0.00
Phymatosorus diversifolius	0.11	0.61	0.00	0.02	0.00	0.04	0.00	0.05	0.95	0.00	0.00	0.00	0.00
Pittosporum eugenioides	0.03	0.84	0.03	0.03	0.42	0.03	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Rubus spp.	0.14	0.53	0.00	0.02	0.26	0.01	0.07	2.53	0.05	0.00	0.00	0.00	0.00
Pseudopanax arboreus	0.05	0.67	0.05	0.03	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Nothofagus fusca	2.02	0.01	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N. solandri	28.69	0.00	0.01	0.05	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Blechnum spp.	0.20	0.05	0.01	0.00	0.03	0.00	0.00	0.00	0.01	0.00	0.00	0.28	0.00
Total			**5.00**	**20.92**	**8.23**	**35.59**	**36.72**	**22.76**	**25.75**	**5.75**	**66.87**	**29.29**	**37.90**

At the landscape scale (Table 4.33, Fig. 4.28) a similar suite of food types (to the community model) contributed high and low values to the individual HSI scores. However, food types such as *Carpodetus serratus*, *Myrsine australis*, *and Sophora microphylla* increased in their contribution. Vegetation communities were ranked differently to the community scale index (Fig. 4.28), this was primarily due to the increased importance of monocotyledon species as a whole, an increase in importance which elevated the scores of the subalpine, pasture, and grass scrubland communities, all of which have high levels of monocotyledon cover.

Table 4.34 Diet contribution model of predictive habitat utilisation. In the null model the percentage contribution of the food type is weighted by its percentage cover in individual vegetation communities.

Food types	**Red beech**	**Mtn beech**	**Matai**	**Broadleaf**	**Mahoe /titoki**	**Bluffs and**	**Pasture**	**Hall's totara**	**Kanuka**	**Subalpine**	**Grass /scrub**
Griselinia littoralis	0.467	0.24	3.564	8.438	1.475	0.034	0	0.205	3.031	0	0
Monocot spp.	0.028	0.298	0.795	0.635	0.263	1.645	11.63	0.822	1.23	20.54	8.955
Melicytus ramiflorus	0	1.887	0.969	2.295	1.76	0	0	0	0.223	0	0
Coprosma rhamnoides	0	0.508	0.092	0.005	0.004	0.007	0.001	0.079	0.603	0	0
Clematis spp.	0	0.001	0.002	0.011	0	0	0	0.012	0.021	0	0
Prumnopitys taxifolia	0.007	0.207	0.543	0	0.442	0	0	0	0	0	0
Coriaria arborea	0	0	0	0	0	0	0	0	0.019	0	0
Sophora microphylla	0.001	0.001	0.166	0.003	0.001	0	0	0.009	0.01	0	0
Cirsium spp.	0	0	0	0.002	0	0	0	0	0.003	0	0.001
Senecio monroi	0	0	0.004	0.026	0	0.002	0	0	0	0	0
Coprosma propinqua	0.001	0.001	0.006	0.04	0.002	0.004	0.005	0.016	0.013	0.014	0.001
Carpodetus serratus	0.039	0.037	0.017	0.004	0.006	0	0	0.016	0.009	0	0
Asplenium spp.	0	0.001	0	0	0.001	0	0	0.003	0.004	0	0
Pseudopanax crassifolium	0.012	0.002	0.004	0	0.001	0	0	0.003	0.006	0	0
Cordyline australis	0	0.001	0	0.004	0	0	0	0	0.007	0	0
Pennantia corymbosa	0	0.004	0	0	0.002	0	0	0.003	0.002	0	0
Myrsine australis	0.008	0.017	0.008	0.013	0.014	0	0	0.002	0.002	0	0
Macropiper excelsum	0	0	0	0	0.001	0	0	0	0	0	0
Coprosma spp.	0.014	0.013	0.026	0	0.002	0	0	0.002	0.041	0	0.001
Pittosporum tenuifolium	0	0	0.001	0.001	0	0	0	0.001	0.001	0	0
Myoporum laetum	0	0	0.003	0.021	0.004	0	0	0	0	0	0
Phymatosorus diversifolius	0	0	0	0	0	0	0	0	0.003	0	0
Pittosporum eugenioides	0	0	0	0	0	0	0	0.001	0	0	0
Rubus spp.	0	0	0	0	0.008	0	0	0.001	0	0	0
Pseudopanax arboreus	0	0	0.001	0	0	0	0	0	0.001	0	0
Nothofagus fusca	0.009	0	0	0	0	0	0	0	0	0	0
N. solandri	0.002	0.013	0	0	0	0	0	0	0.002	0	0
Blechnum spp.	0	0	0	0	0	0	0	0	0	0	0.001
Total	**0.588**	**3.231**	**6.201**	**11.5**	**3.986**	**1.692**	**11.64**	**1.175**	**5.231**	**20.55**	**8.959**

The diet contribution model HSI (Table 4.34, Fig. 4.29) uses percentage contribution to diet rather than preference as the basis for the index scores. It similarly identifies the low quality habitat as red beech, bluffs and screes, and Hall's totara communities (range of values 0.40 – 2.23) (Fig. 4.29). Medium quality habitat groups are identified, a low-medium of mountain beech, mahoe/titoki, kanuka, and matai vegetation (range of values 1.69 – 8.84), and a high-medium of grass scrubland, broadleaf, and pasture communities (range of values 6.15 – 15.29). Similar to the landscape model the subalpine community is identified as the high quality habitat.

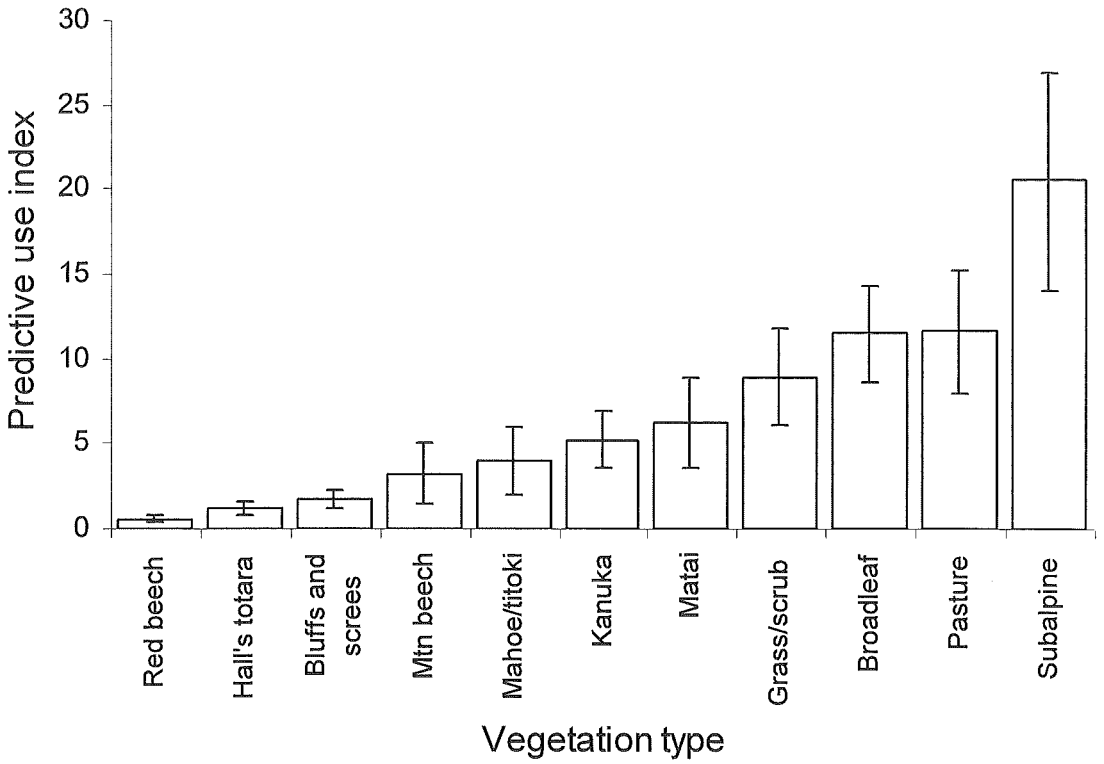


Figure 4.29 Predictive habitat utilisation for the diet contribution model. Mean value, (± 95% Confidence intervals) are presented. Values use the percentage contribution of individual food items to total diet weighted by the percentage area of each plant species in individual vegetation communities.

HSI values for the three different models are recorded in Table 4.35. Community is the community HSI score in which preferences were calculated for the percentage cover of each food type in that community. Landscape is the landscape HSI score in which preferences were calculated for individual food types on the basis of percentage cover for the entire reserve. Log Comm is the community index weighted by the log of the area of each vegetation type. Log land is similarly weighted. Diet contribution model is the HSI score in which no preferences were calculated. Instead percentage contribution to diet was weighted by percentage cover of individual food types in each vegetation community. The weighting of indices by area was done to reflect the size of each potential food resource within the communities. Hence, a community such as mountain beech that has a low community HSI (15.96) is of considerably more importance when viewed in context of the area of the reserve that is covered by mountain beech (~1616 ha). Conversely communities that are ranked highly on a per

hectare (for example matai, Community HSI 22.85) are reduced in importance when considered in the context of area within the reserve (~ 30 ha).

Table 4.35 Habitat suitability indices (HSI) for community, landscape scales and diet contribution model, and weighted indices for area of each vegetation type (see text for full description of individual indices).

Vegetation type	Community	Landscape	Diet ontribution	Area (ha)[1]	Logarea	Lwcomm	Lwland	Ldiet model
Bluffs and screes	6.52	5.75	1.69	363.1	2.56	16.69	14.72	4.33
Broadleaf	27.56	36.72	11.48	780.7	2.89	79.72	106.12	33.21
Grass/scrub	14.28	29.29	8.96	84.1	1.92	27.49	56.37	17.25
Hall's totara	8.70	8.23	1.16	90.0	1.95	17.00	16.05	2.27
Kanuka	20.71	25.75	5.21	243.0	2.39	49.41	61.54	12.43
Mahoe-titoki	15.34	22.76	3.96	66.2	1.82	27.93	41.42	7.21
Matai	22.85	35.59	6.20	29.9	1.48	33.72	52.67	9.15
Mtn beech	15.96	20.92	3.23	1616.2	3.21	51.21	67.15	10.36
Pasture	15.58	37.90	11.64	435.3	2.64	41.11	100.06	30.72
Red beech	3.50	5.00	0.59	162.9	2.21	7.74	11.05	1.31
Subalpine	17.61	66.87	20.55	28.5	1.45	25.62	96.96	29.90

[1] Area of each vegetation community at Isolated Hill Scenic Reserve

Correlation analysis (Table 4.36) reveals few significant correlations between the diet based HSI models and observed habitat selection. Spring use is significantly correlated with the Log Comm and non-significantly with Log Land models (P□ 0.001 and P=0.03 respectively). Of interest, are the patterns apparent in the correlations, autumn, winter, and spring use all have at least one index with which correlation is apparent (albeit non-significant in two cases) (autumn, Log Comm, P=0.12; winter, Log Comm, P=0.17; spring use as above, but also Community, P=0.06). Conversely summer use reveals little correlation with the calculated indices. Similarly post-cull and post-faecal have poor correlation with the calculated indices.

Table 4.36 Spearman rank probabilities of correlation between differing predictive utilisation indices and direct and faecal observation of feral goats at Isolated Hill Scenic Reserve 1995-1997. Significant correlations are indicated in bold. Significance level was set at 0.001 because of multiple comparisons. Note overall use is direct observation for the entire study period.

	Overall (obs)	Overall (pellets)	Pre-use (obs)	Post-use (obs)	Pre-pellet groups	Post-pellet groups	Summer use	Autumn use	Winter use	Spring use
Community	0.21	0.48	0.40	0.68	0.16	0.58	0.43	0.24	0.74	0.06
Landscape	0.85	0.87	0.96	0.90	0.34	0.82	0.52	0.44	0.59	0.45
Diet contribution model	0.82	0.79	0.98	0.84	0.26	0.98	0.58	0.36	0.72	0.45
Log Comm	0.06	0.20	0.11	0.59	0.03	0.63	0.87	0.12	0.17	**0.00**
Log Land	0.28	0.45	0.55	0.42	0.07	0.78	0.46	0.14	0.68	0.03

4.3 Discussion

4.3.1 Habitat selection at the landscape level

Senft *et al.*, (1987) stated that an ungulates' relative preference for plant communities at a landscape scale is generally a linear function of the relative abundance and/or nutritive quality of the preferred plants in the communities. Isolated Hill Scenic Reserve can be defined as a landscape for feral goats in that it is intermediate between individual home ranges and the regional distribution (Dunning *et al.*, 1992) of feral goats throughout Southern Marlborough.

Is the preference for plant communities at Isolated Hill generally a linear function of palatable plant abundance? Figures 4.30 and 4.31 compare various measures of density (direct observation and pellet group density data) with two different models for calculating percentage cover of palatable species (palatable species from Hayward, 1985, and Cochrane, 1994). In neither figure are any of the habitat selection data linear functions of the percentage cover of palatable plant species.

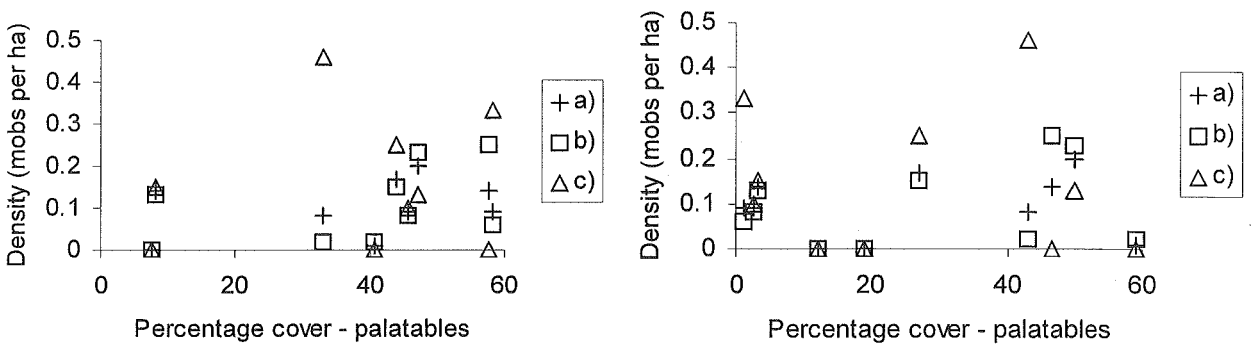


Figure 4.30 Relationship between habitat selection data (direct observation) and percentage cover of palatable plant species for (A) palatable cover calculated from Cochrane (1994), (B) palatable cover calculated from Hayward (1985). The three sets of selection data are a) overall habitat selection, b) pre-cull treatment habitat selection, and c) post-cull treatment habitat selection.

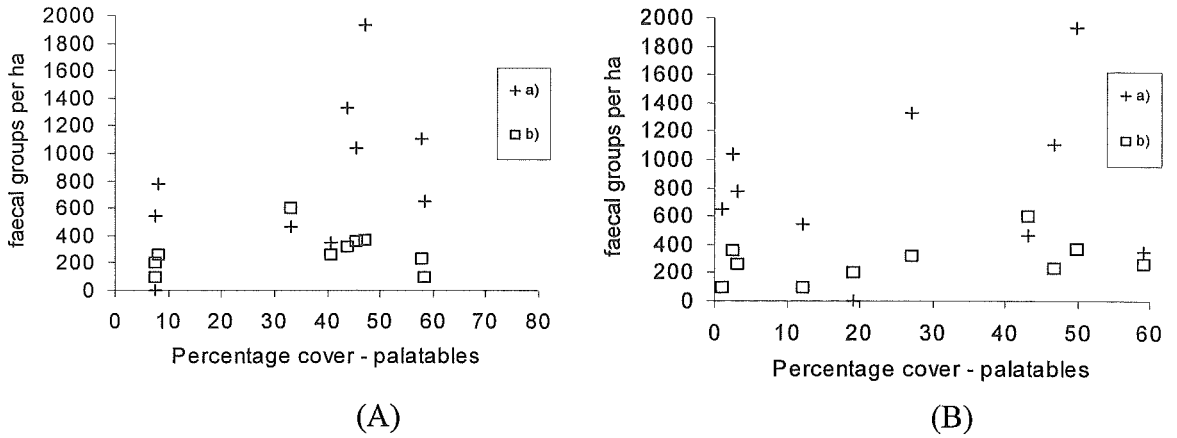


Figure 4.31 Relationship between pellet group data and percentage cover of palatable plant species for (A) palatable cover calculated from Cochrane (1994), (B) palatable cover calculated from Hayward (1985). The two sets of pellet data are a) pre-cull treatment faecal data, and b) post-cull treatment faecal data.

However, rank comparisons between overall use and pre-control treatment habitat selection data and rank percentage cover calculated from Cochrane (1994) reveal two statistically non-significant trends that are interpretable in a linear manner (Fig. 4.32a). Post-cull data however do not follow the same trend. Linear relationships are not apparent for the data modelled against percentage cover values calculated from Hayward (1985) (Fig. 4.32b), this result may reflect Hayward's emphasis on forested habitats only, rather than all habitats that are available to feral goats.

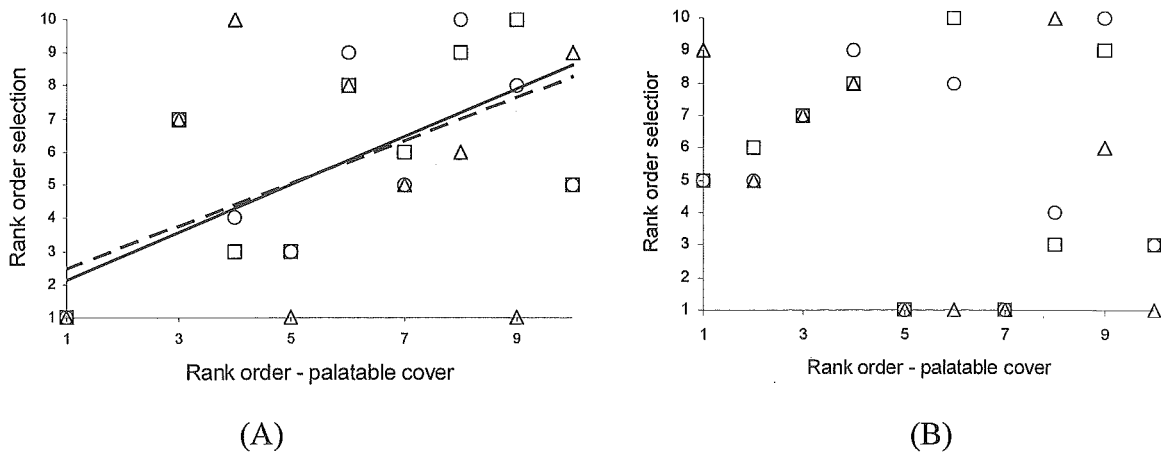
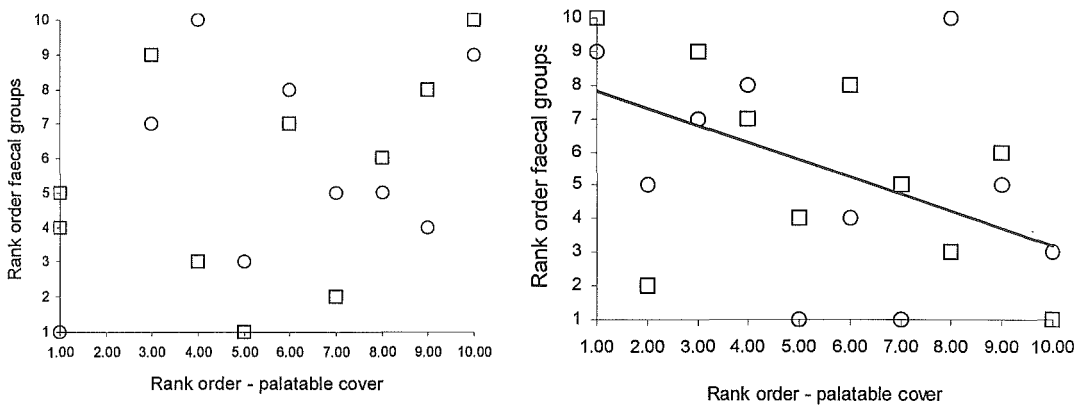


Figure 4.32 Relationship between rank habitat selection data and rank cover of palatable plant species for (A) palatable cover calculated from Cochrane (1994) fitted lines have r^2 values of 0.51 (P=0.14) ---- for pre-cull treatment and 0.42 (P=0.28) — for overall habitat selection, (B) palatable cover calculated from Hayward (1985). The three sets of selection data are (▯ o verall habitat selection, (o) pre-cull treatment habitat selection, and (△) post-cull treatment habitat selection.

In contrast to the direct observation measures of habitat selection, comparison between rank faecal data and rank cover reveals a different trend (Fig. 4.33). Pellet density data (either pre-control treatment data or post-control) showed no relationship to cover calculated from Cochrane (1994) (Fig. 4.33a). Data derived from Hayward (1985) does show a non-significant relationship ($r^2 = 0.26$), unusually though it is a negative relationship. This counter-intuitive finding again is partially attributable to Hayward's restricted coverage of habitats used by feral goats at Isolated Hill Scenic Reserve, but also reflects the limitations of interpreting diet and impact indirectly. Hayward used a browse index as the basis for developing an impact index on individual plant species, a process that potentially reflects the browsing of red deer and possums as well as feral goats.



(A) (B)

Figure 4.33 Relationship between rank habitat selection data and rank cover of palatable plant species for (A) palatable cover calculated from Cochrane (1994), (B) palatable cover calculated from Hayward (1985) fitted line r^2 value of 0.26 for pre-cull faecal data. The two sets of faecal data are (❑) pre-cull treatment faecal data, and (o) post-cull treatment faecal data.

Further evidence of a poor relationship between palatable plant species cover and habitat selection is provided by the HSI models developed for dietary species (Table 4.36). Of the five models (community, landscape, null, and two area weighted indices) only the area weighted community index was statistically significant ($P< 0.001$) for spring habitat selection. In spring goats utilised new grass growth in the improved grassland and grass/scrubland communities, both of which were assessed as having large areas within the study site, and hence affected the relative placing of the communities within the range of index values.

4.3.2 Relationship between density and relative habitat preferences

Riney and Caughley (1959), Atkinson (1964), and Williamson (1975) noted that high use areas for feral goats were generally grassland or grassland interspersed with low shrubs (Williamson further qualified this by noting that drier, sunnier slopes were preferred). This study similarly found that grass shrubland areas were commonly used, however highest use was generally in vegetation types such as broadleaf and mahoe-titoki. Indeed, Riney and Caughley observed the lowest use areas to be forested areas, a finding in complete contrast to this study. The study by Riney and Caughley was based in the Rimutaka Ranges, North Island, in an area of mixed unimproved pasture, scrub, mixed *Nothofagus menziesii* and *Weinmannia racemosa* forest, and fern land, where goats regularly fed in the open. At Isolated Hill Scenic Reserve however, areas of unimproved pasture and scrub are primarily located on the boundaries of the reserve. Hence, part of the difference between the studies can be attributed to the location and scale of the study areas. Williamson (1975) studied feral goat habitat use at Tai Pari, Marlborough Sounds, in a matrix of vegetation that similarly to Riney and Caughley included large areas of improved and unimproved pasture land.

Statistical analysis of seasonal habitat selection did not yield a significant result for season although within-seasons significant differences did occur between mahoe-titoki and red beech vegetation types. The lack of significant seasonal differences is partially attributable to:

1. low sample sizes;
2. the design of the ANOVA analysis (i.e. the omission of some habitats);
3. the selection of core habitats (broadleaf, grass scrubland, and mahoe-titoki, to a lesser extent bluffs and screes) that are selected in all or almost all seasons.

In terms of trends in habitat selection the least number of habitats were selected during autumn and spring. During autumn this potentially reflects behavioural reactions to two factors. During autumn red deer stags are actively sought by hunters, generally in the mountain beech and red beech vegetation types, and avoidance of these vegetation types by feral goats may reflect an anti-predator behaviour. Suring and Vohs (1979) recognised a similar behaviour in their study of Columbian white-tailed deer, which responded to the changing densities of human visitors within the area by utilising more heavily vegetated areas when visitor numbers were high. Winter habitat selection is wider in range and includes the utilisation of improved grassland. During spring habitat

selection was again limited to only four habitats. Grass scrubland and improved grassland accounted for 63.6% of observed mobs (70.3% of individuals) reflecting utilisation of spring growth of grass species. The summer season had the widest range of selected habitats, considerably less selection (24.6%) of grassland type habitats, and greater selection of broadleaf and mahoe-titoki habitats. Kanuka and mountain beech vegetation types were selected during this period, which probably reflects an interaction with climate, as both vegetation types have high cover. Hence, depite offering considerable cover during wetter periods of the year the browse zones of both communities remain damp, a condition that feral goats are known to avoid (Atkinson, 1964; Williamson, 1975).

Temporal habitat selection is also marked in chamois and thar. While Christie (1963) recorded that there was little temporal variation in habitat selection of chamois (although during winter areas of heavy snow were avoided), other authors (Clarke and Henderson, 1984; Forsyth, 1997) have noted distinct and marked seasonal patterns in habitat selection. For example Forsyth (1997) found that chamois used grassland in all seasons (except winter when grassland was covered in snow) but used other areas significantly more during certain periods of the year (for example shrubland was used heavily during winter, less so during spring, autumn and summer). Thar also have pronounced seasonal habitat selection (Tustin, 1990; Forsyth, 1997). Tustin (1990) noted that thar preferred north facing slopes as these areas were less likely to accumulate snow during winter.

Habitat selection (from direct observation data) pre and post-treatment at Isolated Hill Scenic Reserve was not statistically significantly different for treatment. However, pellet density data did show a significantly different effect for treatment ($P<0.001$) and for habitat type ($P<0.001$). At Black Angel Creek, the non-treatment site, direct observations were not significantly different for the two treatment periods. This suggests that habitat is differentially used before and after control. However, it also points to the reliability of information that can be gained from direct observation and pellet density data.

The apparent disagreement between the two methods at Isolated Hill Scenic Reserve can be partially explained through the highly variable counts obtained via direct

observation, indeed Baddeley (1985) states that direct observation of feral goats has little value for estimation of true densities, although arguably direct observation is a useful tool for detecting habitat selection. Pellet density results should also be interpreted with caution as animal behaviour will often dictate where and when faecal deposition occurs (Neff, 1968). Further caution is warranted because of the calculated 12-16% probable limit of error. Notwithstanding this the results suggest that pellet density counts are a better method for investigating habitat selection by feral goats.

From the direct observation data at Isolated Hill Scenic Reserve post-treatment habitat selection favoured areas of the reserve that were either difficult to hunt (kanuka vegetation) or were on the edges of the reserve, and hence less prone to control (improved grassland and subalpine vegetation). The significant differences observed for pellet density data were for broadleaf and mahoe-titoki vegetation, both of which had lower log mean pellet group counts after the imposition of the treatment. The analysis also revealed significant within-treatment differences for red beech and broadleaf vegetation communities in the pre-control treatment. Post-control there were no statistically significant differences between the two vegetation types. This shows that habitat selection post-cull was more evenly distributed between vegetation types suggesting that less favoured vegetation types were being utilised.

These responses post-cull can be represented as a theoretical response model (Fig 4.34) which returns again to the area of habitat selection on the basis of palatable species biomass discussed in section 4.3.1. If a population of feral goats selects vegetation types on the basis of palatable biomass densities could be arranged as in Figure 4.34a,b for the pre-control data (the model also assumes that hunting effort is correlated positively with palatable biomass). Assuming a 50% reduction of population numbers following a control programme, three possible responses can be postulated. Response one is where surviving goats distribute themselves in the same manner as in the original population, but at 50% lower densities across all vegetation types (Fig. 4.34a). In response two, goats transfer to the higher reward vegetation types and away from lower reward vegetation types. No change in density occurs in higher reward vegetation types (Fig. 4.34b). In the final model, response three, the surviving population divides itself into two sub-sets, one group that accepts lower rewards in terms of palatable biomass but is "safer", and another group that moves to higher palatable biomass types. No

change in density is recorded in very high reward vegetation types, and an increase in density occurs in low reward vegetation types (Fig. 4.30b). The observed relationship between measures of habitat selection and palatable plant cover is shown in Figure 4.35. Direct observation measures (Fig. 4.35a) show no clear pattern between pre and post-control. Indeed post-control several habitats with high levels of palatable cover are selected more often. The pellet density data (Fig. 4.35b) show a response similar to that postulated in 4.34a. Densities are proportionally lower in nine of the eleven vegetation communities, which shows that selection (on the basis of pellet density data) behaviour stayed the same pre and post control, but relative densities were reduced.

The effect of hunting on feral goat behaviour has also been observed by Riney and Caughley (1959), Parkes (1984), and Brennan (1992). Feral goats were recorded to seek cover subsequent to shots being fired. Longer term such behaviour may become reinforced within populations and the habitat selection trends observed at Isolated Hill may occur. This is not without precedent in New Zealand, Batchelor and Logan (1963, in Wardle 1984) reported changes in red deer faecal pellet deposition patterns after ground hunting in the Harper Catchment. Pellet density decreased in high altitude grassland and low altitude forest, but increased in high altitude forest. Similar behavioural responses have been reported after intensive helicopter hunting of red deer populations (Wardle, 1984). However both of these examples represent situations where control has been ongoing for several years, wheras the situation at Isolated Hill Scenic Reserve represents a one-off intensive control campaign.

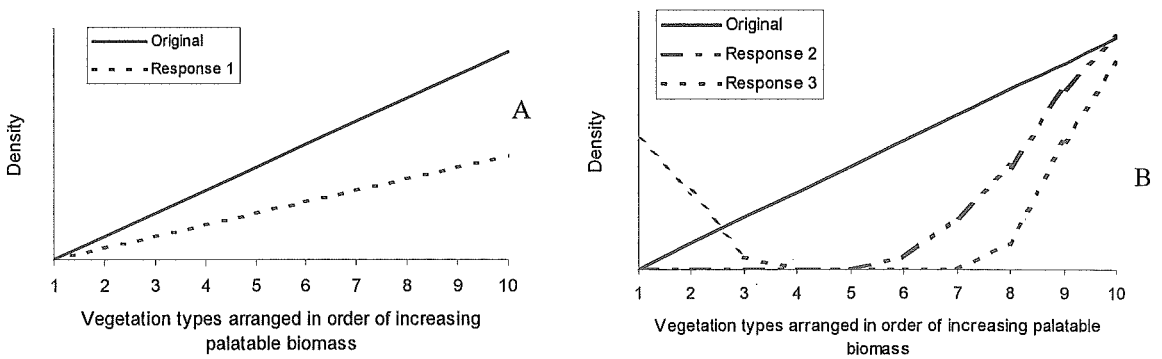


Figure 4.34 Theoretical feral goat density responses to a 50% reduction in numbers of feral goats in a reserve.

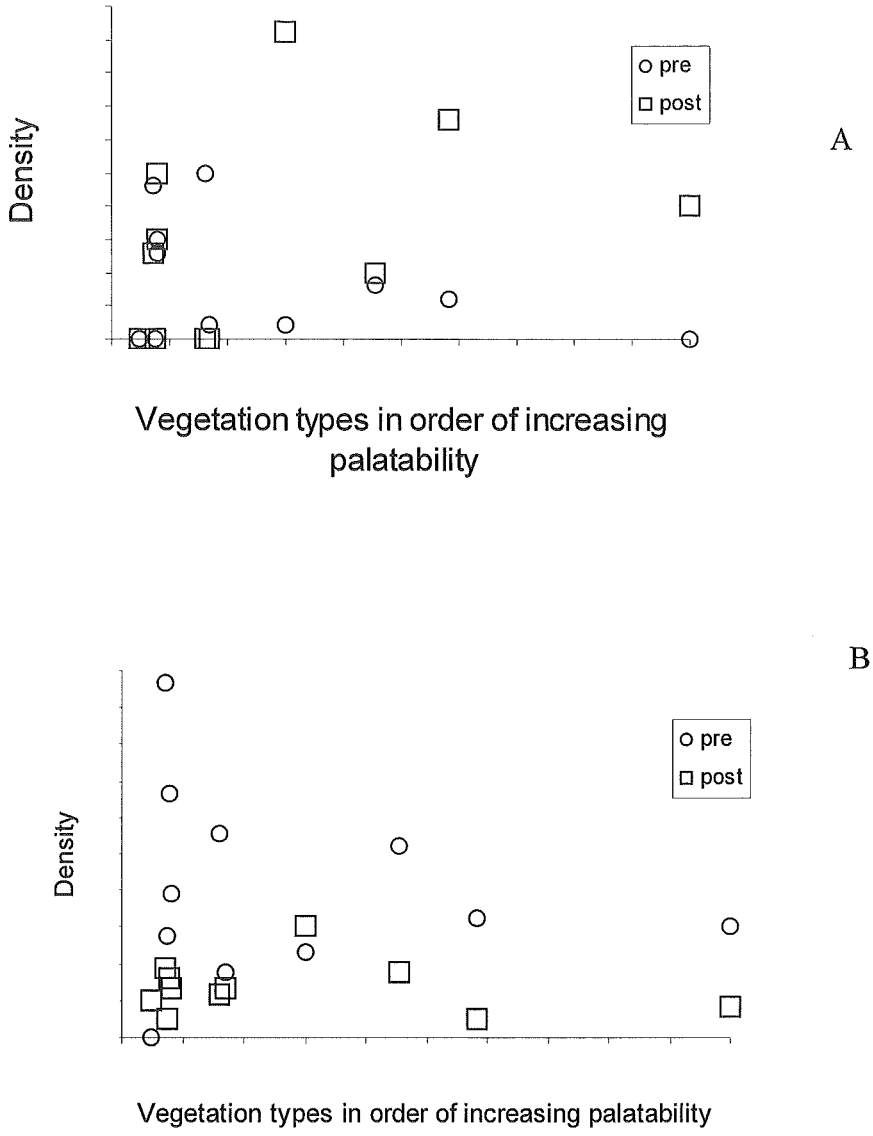


Figure 4.35 Observed relationships between habitat selection measures and palatable biomass of vegetation communities at Isolated Hill Scenic Reserve. A) is for pre and post control direct observation. B) shows pre and post pellet density data.

Feral goat densities at Isolated Hill Scenic Reserve are comparable to other areas of New Zealand. Isolated Hill Scenic Reserve densities (Table 4.37) had a range of values of 0.00 – 0.22 mobs per ha (for different vegetation types), and a mean overall density of 0.06 feral goat mobs per ha for all vegetation types. If an average value of 2.00 goats per mob is used then this shows a range of 0.00-0.44 goats per hectare for different vegetation communities and an overall density of 0.12 goats per ha for the entire reserve. Parkes (1993) noted a variety of densities for feral goat populations throughout New Zealand. Recorded densities were 0.3 goats per ha from Great Barrier Island, Mt

Egmont National park, 0.1 per ha, West Motu River 0.1 per ha, and Wairau, 0.05 per ha. Brennan (1992) recorded densities of 0.13-0.14 feral goats per ha for grassland habitats and 0.16-0.21 feral goats per ha for forest habitats at a site approximately three km from Isolated Hill. Densities for chamois have also been reported, ranging from 0.02 – 0.04 animals per hectare (Christie, 1963; Clarke and Henderson, 1981).

Table 4.37 Range of feral goat densities at Isolated Hill Scenic Reserve. Densities are expressed in number of mobs per hectare. Minimum and maximum numbers are one standard error either side of the median value. Overall average value is presented in bold (± 1 S.E.).

Vegetation type	Median number of goat mobs per ha	Minimum number of goat mobs per ha	Maximum number of goat mobs per ha
Bluffs & screes	0.13	0	0.26
Broadleaf	0.20	0.13	0.23
Grass/scrubland	0.09	0.06	0.13
Hall's totara	0	0	0
Improved grassland	0.09	0	0.33
Kanuka	0.02	0	0.27
Mahoe-titoki	0.15	0.09	0.40
Matai	0	0	0.50
Mountain beech	0	0	0.05
Red Beech	0	0	0
Subalpine	0	0	0.20
Average value	**0.06 (± 0.02)**	**0.03 (± 0.01)**	**0.22 (± 0.05)**

4.3.3 Optimal foraging and habitat selection – diet or predator avoidance?

Can the patterns of habitat selection by feral goats actually be attributed to factors that are as simple as diet or predator avoidance? Do feral goats select habitat in a manner that maximises their net rate of energy gain? Is there an interaction effect between foraging and predator avoidance?

Ollason (1987) argues that such questions in the context of heterogeneous landscapes ignore the ability of an animal to learn about its environment, and that any attempt to distinguish between learning and foraging is itself futile. This study has not attempted to differentiate between the two, indeed an assumption of this study is feral goats do have knowledge about the landscape in which they live. The patterns of habitat selection observed within the period of this study reflect at the population level, behaviours that have been changed in relation to resources located within the Isolated Hill Scenic Reserve. Significant differences in habitat use were found for seasonal habitat selection (P= 0.002) (direct observation) and for pellet group density data

($P<0.001$). In this, the study agrees with the assertion of Schoener (1987) that learning should be incorporated into any investigation of optimal foraging.

What evidence is there for diet or predator avoidance acting as the parameter that is dictating habitat selection at Isolated Hill Scenic Reserve? I found positive correlations between habitat selection and palatable species, both for total cover, and for cover within the browse tier. Habitat selection is also positively correlated with abundance of individual preferred dietary species (*Griselinia littoralis* and *Melicytus ramiflorus*) and negatively with unpalatable species cover (*Nothofagus* spp.). In terms of predator avoidance (hunting difficulty is used here as an indicator) only in spring is there any correlation with hunting, this is a negative correlation (the four habitats selected were all considered relatively easy to hunt).

Many parameters have been suggested that might account for ungulate foraging behaviour (and hence habitat selection). These include forage biomass concentration (Senft *et al.*, 1987, Wallace *et al.*, 1995), patch quality (Clarke *et al.*, 1995), thermal relationships (Bowyer *et al.*, 1998), and predation risk (Bowyer *et al.*, 1998). Studies of ungulates diet, predator avoidance, and mate selection (Dunbar *et al.*, 1990; Focardi *et al.*, 1996; Bowyer *et al.*, 1998) suggest that habitat selection constrained by conflicting demands is still possible through the process of choosing patches within heterogeneous landscapes that minimise the ratio of the conflicting demands (Bowyer *et al.*, 1998). At Isolated Hill Scenic Reserve if such a strategy were employed by feral goats (*i.e.* there was a trade-off between diet and predation risk) then the expectation would be that some goats would select habitats that provide protection against hunting, at the expense of food. Mysterud and Ims (1998) note that many habitat patches will not have favourable combinations of diet and protection values, hence coarse grained species (a species that selects resources in proportions different from those in the environment (Rosenzwieg, 1981)) will respond by selecting habitat patches that either provide food or provide protection. At Isolated Hill, feral goats clearly select habitats (with the exception of bluffs and screes) that have a rank hunting difficulty of less than six (*i.e.* are easy to hunt). When percentage cover of palatable species (from the data calculated from Cochrane (1994)) is compared with hunting rank, habitats that are most often selected (for example broadleaf, grass/scrubland, mahoe-titoki, matai habitats) are those with high palatable cover scores and low rank hunting difficulty (Fig. 4.31). Using the

habitat relationship models as a test of this shows that diet variables were important predictors for the multiple regression models (broadleaf total cover, 26.7% of models, broadleaf as a proportion of browse, 25.9% of models, *Nothofagus* browse, 23.0% of models, total palatable cover, 19.3% of models and broadleaf cover in the browse tier, 17.8%). Hunting difficulty however was only incorporated in 3% of all models.

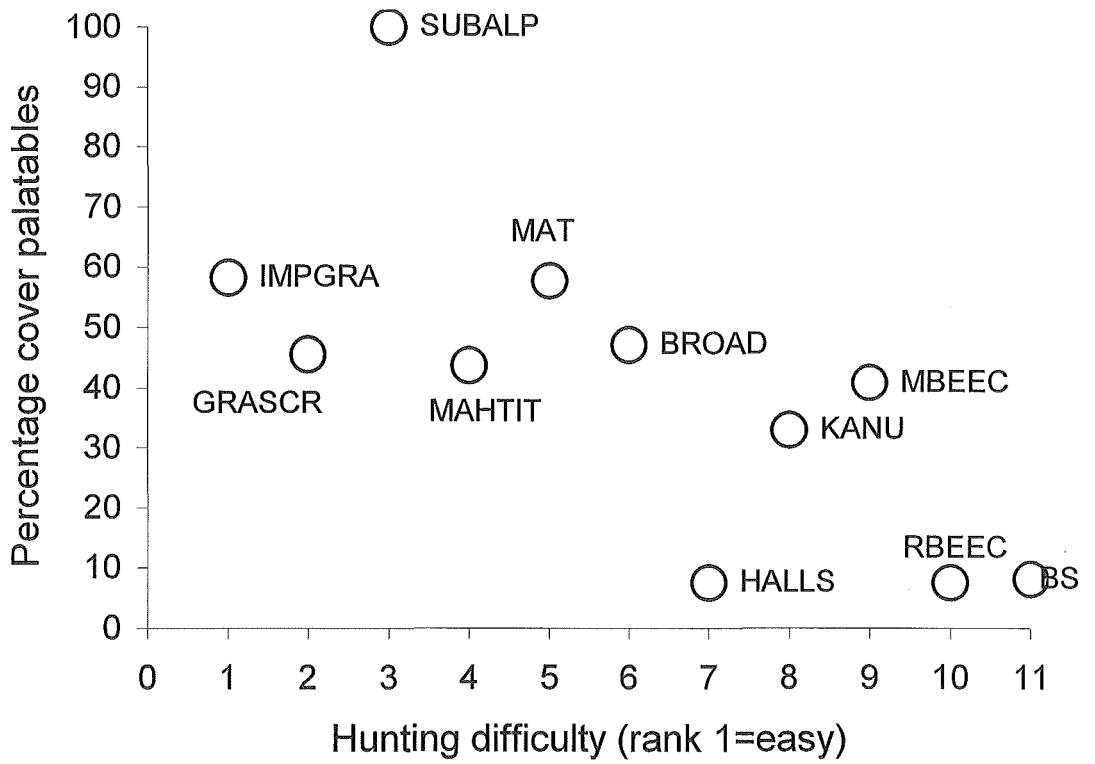


Figure 4.36 Relationship between total cover of palatable species (calculated from Cochrane, 1994) and rank hunting difficulty. Habitat codes are BS, bluffs and screes; BROAD, broadleaf; GRASCR, grass/scrubland; HALLS, Hall's totara; IMPGRA, improved grassland; KANU, kanuka; MAHTIT, mahoe-titoki; MAT, matai; MBEEC, mountain beech; RBEEC, red beech; SUBALP, subalpine.

Ideal habitat for feral goats would be vegetation communities that combine a high percentage cover of palatable species with a high rank hunting difficulty. Such communities would be located at the top right corner of Figure 4.36. Poor habitat would be vegetation communities that combine a low rank hunting difficulty with low cover of palatable plant species (the bottom left area for Fig. 4.36). Habitat selection would initially be of communities that combined safety and diet, but as palatable biomass was reduced goats would then select communities that were more dangerous but offered greater food reward. This mirrors the marginal value theorem (Charnov, 1976) in which high reward communities are utilised until the reward level within them

is similar to or below that of other communities. Animals then select the next most rewarding habitat. Of note in Figure 4.36 is the broad band of habitats that occupy the central area of the figure. These habitats therefore have approximately equal benefit/risk ratios. Holbrook and Schmitt (1988) caution that simple analyses of predation risk and food reward may overlook complex interactions between risk and food reward, interactions that occur at several spatial and temporal scales.

Clarke *et al.,* (1995) noted that herbivores can discriminate between patches and that this can be related to prior experience, or potentially to prior use by other ungulates. Wallace *et al.*, (1995) noted that where food resources were relatively homogeneous a random feeding pattern occurred. This is supported by the work of Focardi *et al.,* (1996), who found that fallow deer had a foraging pattern that could best be described as a biased random walk. Focardi *et al.,* (1996) stated that food resources for ungulates tended to be common and of poor nutritive quality. Their study found that fallow deer left patches even though food remained which suggested that there was a marginal value after which deer moved to the next station. The findings of Wallace *et al.*, (1995) and Focardi *et al.*, (1996) contrast with those of this study. At Isolated Hill homogeneous food resources do not exist. Support for diet being the determining factor in habitat selection by feral goats at Isolated Hill Scenic Reserve is found in the vegetative cover values of principal and preferred dietary species in the habitats that are selected. In several of the rank correlations between ecological correlates and habitat selection *G. littoralis*, *M. ramiflorus*, and *Nothofagus* cover are significantly correlated. In the case of *G. littoralis* and *M. ramiflorus* Hayward (1985) and Cochrane (1994) both recorded these two species as highly preferred by feral goats. Both studies also noted that *Nothofagus,* while occasionally browsed (Hayward, 1985) or consumed (Cochrane, 1994) was an unpreferred species. This is seen in the low use of mountain beech habitat, even though the habitat has a high level of *M. ramiflorus* cover. In the analysis of habitat models, diet-related variables accounted for the five most important variables (total percentage contribution 37.53), and overall contributed 61.48% of the variables in the respective models (Table 4.22). Brush and Stiles (1986) in a model of habitat selection and abundance of birds found that birds were the most abundant at areas of highest prey density. They suggested that prey abundance was an excellent predictor at a number of levels.

Such relationships are however, not necessarily causal. Indeed, actual behaviour often does not fit the predictions of optimal foraging theory (Focardi *et al.,* 1996). Models may only predict average value, and little of the variation in selection for daily or other temporal periods. Ward (1993) noted that the interpretation becomes one of scale: if a population as a whole is to be characterised then a measure of central tendency is appropriate; if however, sub-populations are the unit of interest, the range of behaviour is the appropriate measure.

4.3.4 Habitat models

Habitat models work on the broad assumption that a species will select and use areas that are best able to meet biological requirements (Schamberger and O'Neil, 1986). Hence, within this work the focus has primarily been on testing two factors that may account for feral goat habitat selection, diet and predator avoidance. The habitat selection models developed here are typical of level one models (Van Horne, 1983), in other words they are models developed specifically for a single species at a particular site. The models developed here have also emphasised selection and relative use rather than absolute densities of feral goats. Patterns of relative selection or use are tied more directly to habitat conditions than is density, as density can be sensitive to a variety of factors other than habitat quality (Lancia *et al.*, 1986). Diehl, (1986) found that while community assemblages of birds could be predicted easily from observations, densities of individual species were more difficult to predict. Diehl attributed this partially to variation in competitive ability of individual species. Schamberger and O'Neil (1986) stated that relative abundance is best used when a large number of sample sites are incorporated, the data represents long-term abundance, unusual events (for example extreme weather) can be screened out when the event affects only subsets of the sample, and field methods are consistent. Further, habitat selection models may be limited statistically through violating the assumption that resource units are collected randomly and independently (Millspaugh *et al.*, 1998). This is particularly problematic for feral goats, as due to strong social structures, often the incidence of one goat will not be independent of another. Where dominant nannies or billies are observed, sub-dominant goats will be arranged in a non-random manner near them. Hence, for feral goats any model of habitat selection should be based upon mob numbers and not individual numbers *per se*.

The multiple regression habitat models showed that diet variables were more important than the physical variables slope and aspect. Altitude was the most important of the three measured physical variables at 16.3% of all models. Two indices of diversity (Berger-Parker and Margalef's) were also important variables in the models (in 17.8% and 16.3% of models respectively) although this can be explained by linking them to habitats that had high cover for palatable species (improved grassland and grass scrubland communities), or unpalatable species (mountain beech and red beech communities). Novellie and Winkler's simple HSI based on dietary preferences and percentage cover was a poor index in terms of predicting habitat selection (Table 4.36, only one significant result). The poor ability of the diet HSIs to predict habitat selection is attributable to diet being only one of many stimuli that direct habitat selection (Wiens, 1985)

The habitat selection models developed in this study are not intended as definitive measures of feral goat behaviour at Isolated Hill Scenic Reserve, instead they make the strong point that habitat selection and hence utilisation is not spatially or temporally homogeneous. This is especially important for the management of a feral animal such as goats, which are the focus of considerable national and international effort in terms of mitigating conservation impacts.

4.4 Conclusion

This chapter aimed to investigate habitat selection of feral goats at Isolated Hill Scenic Reserve, and how it related to diet and hunting. Specific findings of the chapter were:

1. direct observation and faecal pellet density data showed that feral goats differentially selected habitats at Isolated Hill Scenic Reserve and Black Angel Creek. Habitats that were selected most were broadleaf, mahoe-titoki, and matai. Habitats that were selected the least were Hall's totara, red beech, and mountain beech;

2. direct observation of habitat selection by feral goats at Isolated Hill Scenic Reserve and Black Angel Creek revealed no significant changes in habitat selection despite a

major control programme. However pellet group density data did show significant differences pre and post-control. Pellet data showed that after the control programme feral goats used habitats that provided greater cover;

3. multiple regression models of habitat selection using a variety of different site variables for individual habitats were able to predict observed habitat selection. Individual variables were generally poor at predicting habitat selection.

4. a simple habitat suitability index that predicted habitat selection on the basis of feeding preferences and percentage cover of different plant species did not produce statistically significant results. This coupled with investigation of rank hunting difficulty shows that diet is an important variable in predicting habitat selection, but is not the only variable that needs to be considered.

Chapter 5 - Feral goat habitat selection: implications for conservation management

5.1 Introduction

Feral goats and introduced mammals in general within New Zealand provide a fascinating area for research, however, as Coblentz (1990) noted this fascination should not be at the expense of the environment. Coblentz (1990) suggested that feral animals provide opportunities for research by direct manipulation and management. Townsend (1991) stated that high priority must be given to the study of exotic species within New Zealand, although the research should directed towards understanding the mechanisms of invasion and spread across landscapes. Having elucidated the habitat selection of feral goats at Isolated Hill Scenic Reserve and potential approaches in terms of pest-habitat modelling, how can that knowledge be incorporated generally into the issue of feral goat control in New Zealand?

Stephens (1999) states that conservation is primarily an asset management business and that the current state of the asset can be expressed as the well being of the conservation portfolio. Using this approach impacts associated with conservation assets can be characterised as threats, beneficial, or neutral. Stephens (1999) notes that a major problem for New Zealand is our lack of a national inventory of biodiversity, which prevents measurement of natural heritage status, measurement of conservation benefit achieved, and identification of the most cost – effective conservation projects. Stephens suggests that there are two approaches to producing an inventory of biodiversity, either catalogue taxonomic units or alternatively catalogue ecosystems and landforms. Houston and Schreiner (1995) state that the way a natural area is managed similarly falls into this dichotomy, either the area is managed for a goal of conservation of biological entities or it is managed to preserve natural ecosystems and ecosystem processes.

Irrespective of which method of biodiversity inventory or management is adopted, exotic species have the potential to impact in a negative fashion on both. Hence,

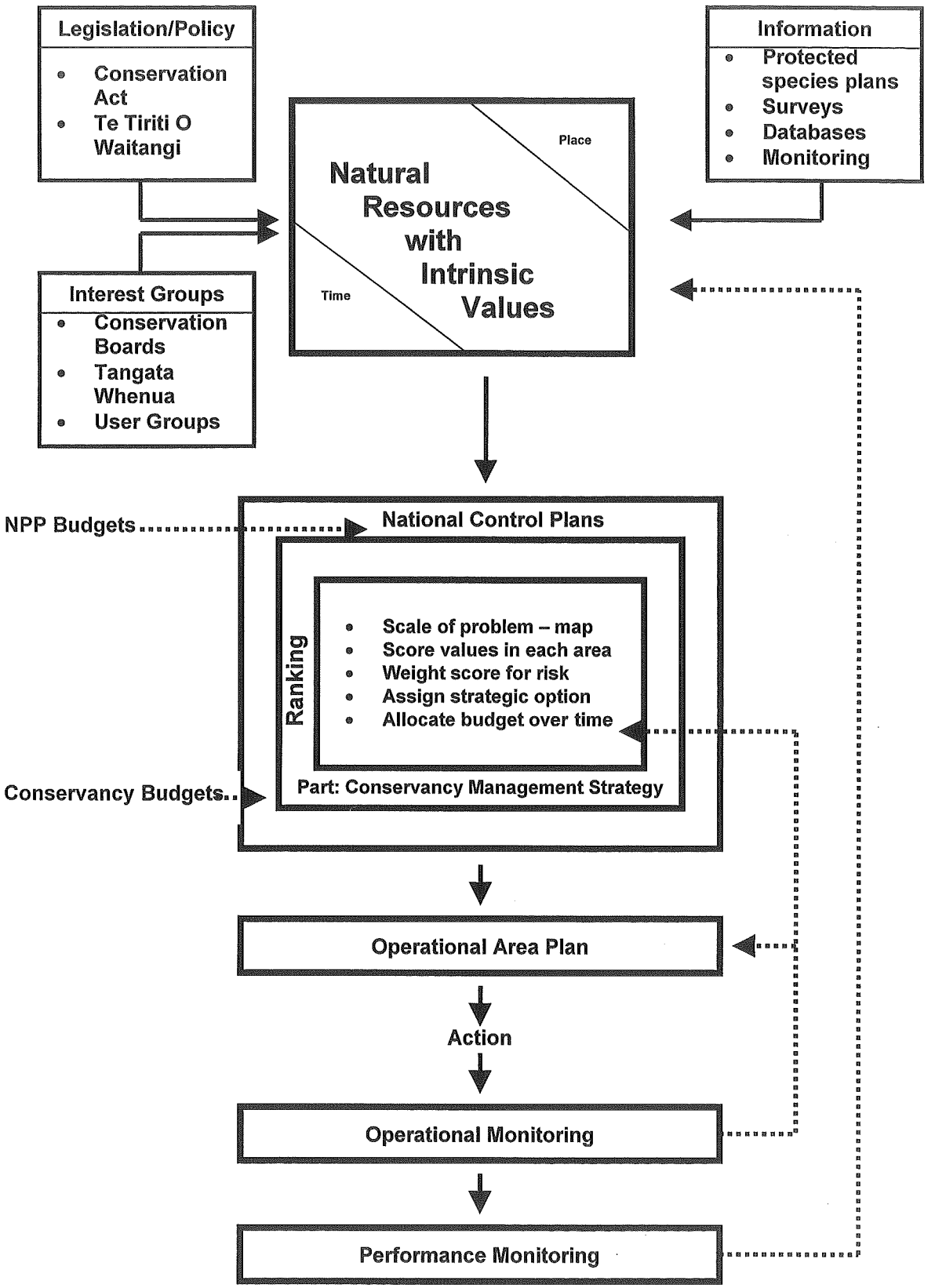


Figure 5.1 National planning structure for feral goat management in New Zealand, proposed by Parkes (1993). Solid lines indicate direct flow on linkages. Dotted lines show feed-back loops from operational level to conservancy and national level.

strategic and tactical tools are required to ensure the impacts are minimised as much as possible. In New Zealand three strategic options have been identified to ameliorate the impact of feral goats (Department of Conservation, 1998). The three options are:

a) limitation of dispersal and introduction (this can be enacted through the Wild Animal Control Act 1977, and Biosecurity Act 1993, but more importantly public education);
b) eradication (only feasible when: re-infestation probability is low, culling rate is higher than replacement rate, all targeted animals are at risk, and there is the genuine will to eradicate (Parkes, 1990a);
c) sustained control (which should act to reduce feral goat density below a pre-set target that is linked in some way to a response by the conservation resource under threat).

In the past feral goat control has been co-ordinated nationally via the allocation of National Priority Pool (NPP) funding (Parkes, 1993). Historically this has only been sufficient to enact control operations for approximately 33% of conservation lands, hence priorities have been determined through ranking systems that consider the importance of a conservation resource and threats (Parkes, 1993). Parkes (1993) proposed a national planning structure (Fig. 5.1) for feral goat management in New Zealand which incorporated inputs from outside agencies, allowed for the national co-ordination of prioritisation and ensured that operational programmes were well planned and performance monitored. However no clear input for regional variance in feral goat distribution or habitat utilisation was identified, in particular for operational control programmes at the level of conservancies or area offices.

This chapter is concerned with control operations by Department of Conservation staff on feral goats in Isolated Hill Scenic Reserve. The chapter aims specifically to:

1) investigate whether percentage of kill locations in each habitat matches habitat selection by feral goats;
2) investigate how hunters perceive hunting difficulty in different habitat and whether hunting difficulty is related to the percentage of kill locations;
3) investigate whether different categories of hunter are more or less cost-effective in terms of average cost per kill;

4) investigate habitat, seasonal, and weather effects upon hunting. The primary interest is whether different habitats produced greater average kill rates, whether particular times of the year produce greater average kill rates, and whether weather affects average kill rate.

5.2 Methods

Data for this chapter were collected from four sources. Hunting kill locations were collated from hunting kill overlays provided by Department of Conservation hunting staff. Grid references were recorded using the NZMS 260 Map series, then vegetation at the kill site was established via aerial photographs and the vegetation map produced in Chapter 3. A total of 450 kill locations were recorded, from which percentage of total kill in each vegetation type was established. The figures were compared to observational data and pellet density data. Spearman rank correlation was used to test for trends between data.

The Renwick Area Office, Nelson/Marlborough Conservancy, Department of Conservation, provided information on all hunting activity within the Marlborough area of operations for the period 1 July 1991 – 24 June 1996. Data provided were hunter, financial year, date, operational area (for example Isolated Hill), sub-area (for example Isolation, an area within Isolated Hill Scenic Reserve), category of hunter (Department of Conservation, casual, Task Force Green), total hours hunted, number of days in field, and number of goats killed. From these data the average number of kills per hour hunting, cost per kill, and total cost were calculated.

Hunter ability, seasonal and habitat effects were calculated from the Isolated Hill Scenic Reserve hunting return sheets that hunters provided at the end of an operation. The sheets gave information on the number of hours hunted, number of goats killed, type of vegetation hunted in and weather conditions. Mean kills per hour were calculated by dividing total hours hunted by the number of goats killed per field operation. The data were for a total of 1351 hours of hunting and 1459 killed goats. Seasonal, habitat, and weather effects were calculated using the same data set. Significance was analysed using one way analysis of variance (ANOVA).

Hunters were also approached directly and asked to fill in a questionnaire about difficulty of hunting at Isolated Hill Scenic Reserve. Hunters were asked to score each vegetation type between one and five (one very easy, three average, five very hard) in terms of difficulty to hunt. Scores were then averaged and allocated a rank hunting difficulty. At the time of the survey Hall's totara had not been described as a discrete vegetation type, hence for the analysis this was allocated an overall score of three. Hall's totara is typically a relatively open vegetation type with steep slope, similar in terms of trafficability to matai and broadleaf vegetation (cf Table 4.1 for comparison of visibility between communities). It is not as densely vegetated as kanuka, and is not as steep and exposed as bluffs and scree slopes.

A simple cost model was developed from travel costs, ammunition costs and daily wage allowances to allow cost per kill to be calculated for individual hunters. The equation developed was:

$$CPK = \frac{(t + a + w)}{g} \qquad \text{Eq. 5.1}$$

where t is vehicle travel

$t = vehicle\,kilometres \times vehicle\,rate$

where a is ammunition allowance issued to hunters

$a = number\,rounds \times cost\,per\,round \times number\,of\,goats\,killed$

where w is wage/salary cost

$w = wage/salary\,rate \times number\,of\,days\,in\,field$

where g is the number of goats killed per operation

For Isolated Hill Scenic Reserve the equation for cost per kill (CPK) had inputs of 80 km of travel at \$0.70 km^{-1}, ammunition costs of three rounds at \$0.465 $round^{-1}$, and wage costs of \$110 day^{-1}.

$$CPK = \frac{((80 \times \$0.70) + (3 \times \$0.465 \times g) + (\$110.00 \times number\,of\,days\,in\,the\,field))}{g} \qquad \text{Eq. 5.2}$$

5.3 Results

5.3.1 Allocation of feral goat kills at Isolated Hill Scenic Reserve

Percentage distribution of feral goats kills in different vegetation types (Table 5.1) reveals that most goats were killed in grass/scrubland and mahoe-titoki vegetation types. Vegetation types that had the least percentage of kills in them are subalpine, red beech, and bluffs and screes vegetation types. Spearman rank correlation between the different measures showed that percentage of kills was significantly correlated with percentage of pellet groups ($P<0.05$), but was not significantly correlated with percentage of observations of mobs ($P=0.19$), nor percentage of observation of individual goats ($P=0.18$).

Table 5.1 Percentage distribution of kills from Isolated Hill Scenic Reserve 2 December 1991 – 17 February 1997 compared to calculated feral goat habitat selection from this study. All observational and pellet data are for the pre-cull treatment.

Vegetation type	Percentage of kills	Percentage of observations mobs	Percentage of pellet groups pre-cull	Percentage of observations individuals
Bluffs & Screes	2.4	8.6	9.2	7.6
Broadleaf	7.6	28.5	31.5	28.4
Grass/scrubland	24.3	30.5	6.2	36.2
Hall's totara	2.8	0	3.4	0
Improved grassland	3.9	3.7	3.2	3.0
Kanuka	7.8	2.8	3.4	1.3
Mahoe-titoki	28.7	19.0	30.0	15.8
Matai	14.6	1.5	8.5	2.5
Mountain beech	5.9	1.0	2.3	0.8
Red beech	1.1	0	0.6	0
Subalpine	0.9	4.6	1.7	4.6

5.3.2 Hunting difficulty at Isolated Hill Scenic Reserve

Analysis of hunting difficulty (Table 5.2) shows that open vegetation types with high visibility are considered easiest to hunt except in the case of Bluffs and screes. Bluffs and screes were ranked at 11 (*i.e* the most difficult) which reflected the difficulty associated with traversing this vegetation type. Forested vegetation types were ranked from four through to ten, lower ranks (mahoe-titoki, matai and broadleaf) are typically more open and generally have less vegetative cover in the browse tier than the forested vegetation types that were ranked as more difficult to hunt (cf. Table 4.18a-d).

Comparison of percentage of kills to rank hunting difficulty reveals a negative relationship (Fig. 5.2). When subalpine and improved grassland habitats are removed

(both have low rank hunting difficulty and low contribution to percentage allocation of kills) the relationship reveals that the greatest percentage of kills occur in habitats that have lower rank hunting difficulty levels (three vegetation types grass/scrubland, matai, and mahoe-titoki contribute 67.6% of all kill locations) (r^2=0.75, P=0.175). Conversely, few kills were recorded in vegetation types that have high rank hunting difficulty levels. The removal of subalpine and improved grassland habitats can be justified as both habitats are only hunted opportunistically by Department of Conservation staff while moving to and from other hunting areas.

Table 5.2 Analysis of difficulty of hunting in vegetation types at Isolated Hill Scenic Reserve. Hunters were asked to rank vegetation types on a score of 1-5 (1 very easy, 3 average, 5 very hard). Hall's totara was not identified in the survey of nine hunters, hence was included at a later date and allocated an average score of three.

	Respondent											
Vegetation type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Average**	**S.E.**	**Rank**
Improved grassland	1	1	1	2	1	1	1	1	1	1.11	0.11	1
Grass/scrubland	1	3	1	2	2	2	2	1	2	1.78	0.21	2
Subalpine	2	1	2	2	2	2	2	2	2	1.89	0.14	3
Mahoe-titoki	3	1	2	2	4	3	3	4	3	2.78	0.31	4
Matai	3	2	3	2	3	4	3	3	3	2.89	0.21	5
Broadleaf	3	2	3	3	3	4	3	3	3	3.00	0.19	6
Hall's totara										3		7
Kanuka	3	5	4	4	4	5	4	2	4	3.89	0.29	8
Mountain beech	4	5	4	3	3	4	4	5	4	4.00	0.22	9
Red beech	4	5	4	4	4	4	4	4	4	4.11	0.11	10
Bluffs and screes	4	5	5	4	5	3	5	5	2	4.22	0.34	11

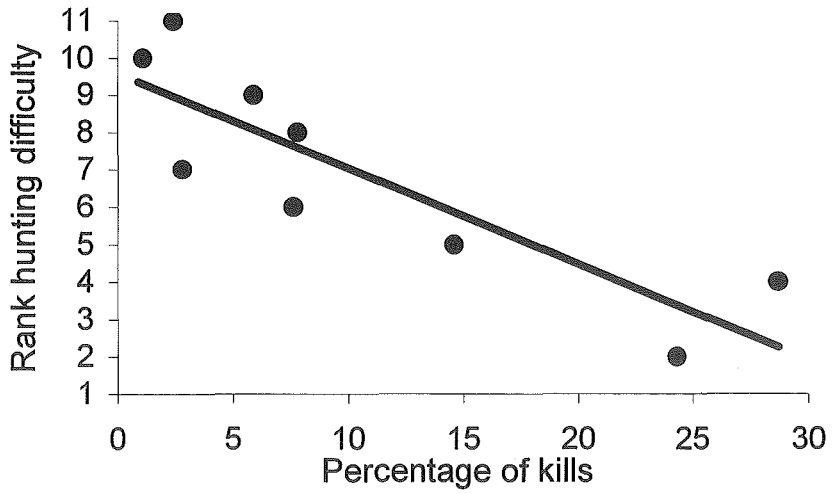


Figure 5.2 Relationship between rank hunting difficulty and percentage of kills in nine different vegetation types at Isolated Hill Scenic Reserve (r^2 = 0.75, P=0.175). Data are for Isolated Hill Scenic Reserve hunting 2 December 1991 – 17 February 1997.

The relationship between hunting difficulty and percentage of kills is interesting as it reflects hunter perceptions in two manners. First it reflects the perception that grass/scrubland and mahoe-titoki forest are the most used by feral goats, and secondly it reflects the perception that beech and kanuka vegetation are difficult to hunt in (as they have considerable vegetative cover in the browse tier) and are not often used by feral goats. Bluffs and screes are ranked as highly difficult primarily because of the danger involved in traversing them.

5.3.3 Hunter effectiveness at Isolated Hill Scenic Reserve

For the comparison of hunter type, hunters were categorised into three different groups. The three groups were Task Force Green (long term unemployed people employed by the Department of Conservation through a work scheme), Department of Conservation staff, and casual staff who are generally contractors who specialise in animal control (Fig.5.3). ANOVA analysis for differences between type of hunter and cost per kill was significant ($F_{2, 125} = 4.50$, P=0.013). Post-hoc analysis showed the significant difference was between Task Force Green and casual hunters. Analysis of hunter type versus average cost per kill (Fig. 5.6) suggests that Task Force Green hunters operated at considerably greater cost than Department of Conservation staff and casual hunters (Fig. 5.3).

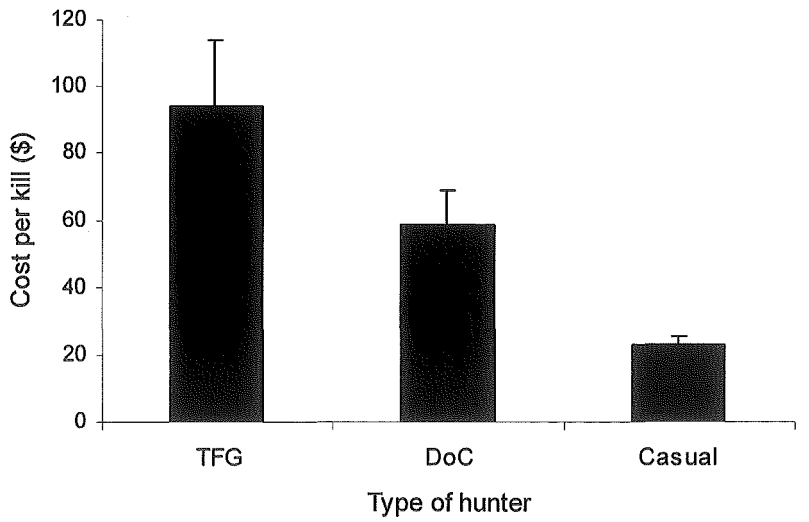


Figure 5.3 Mean cost per kill (± 1 S.E.) for 3 different categories of hunter operating in Isolated Hill Scenic Reserve.

Differences in average kill rate between seasons (Fig. 5.4) were apparent with autumn producing the lowest number of average kills per hour, 0.71 ± 0.12 (1 S.E.), and summer producing the highest number, 1.25 ± 0.14 (1 S.E.). Winter and spring had intermediate average kill rates of 1.08 ± 0.14 (1 S.E.) and 1.00 ± 0.13 (1 S.E.) respectively. However ANOVA analysis showed no significant result ($F_{3, 197} = 1.41$, P=0.24).

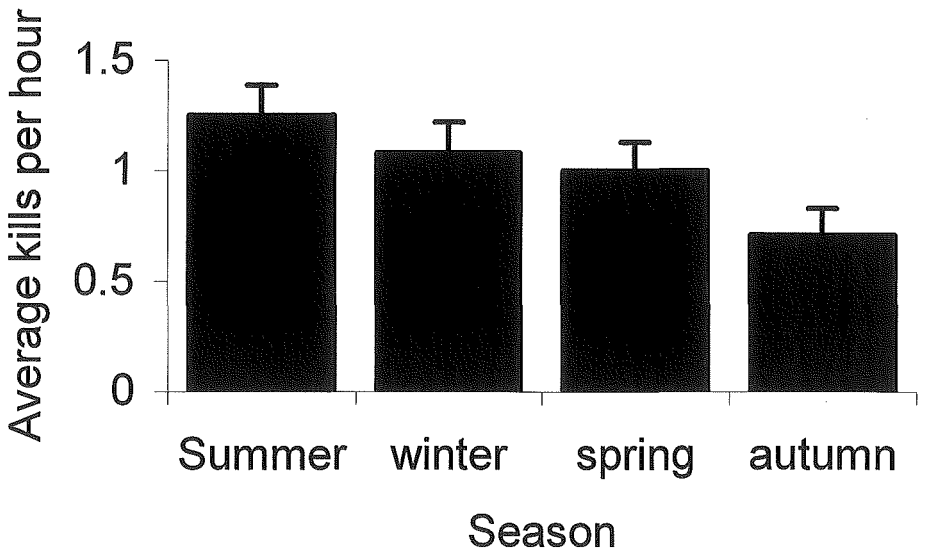


Figure 5.4 Seasonal differences in the average number of kills per hunter hour (mean values ± 1 S.E.) at Isolated Hill Scenic Reserve 2 December 1991 – 17 February 1997.

Analysis of average kills per hour for the four vegetation types identified in the hunter returns (Fig. 5.5) reveals a range from 0.68 ± 0.38 (1 S.E.) for matai vegetation to 1.27 ± 0.17 (1 S.E.) for grass/scrubland vegetation. No significant differences were found between habitats ($F_{3,197} = 1.319$, P=0.27), although the grass/scrubland habitat's higher average kill rate is attributable in part to visibility within the habitat. Hunters are able to observe greater areas, and feral goats if present are more likely to be seen.

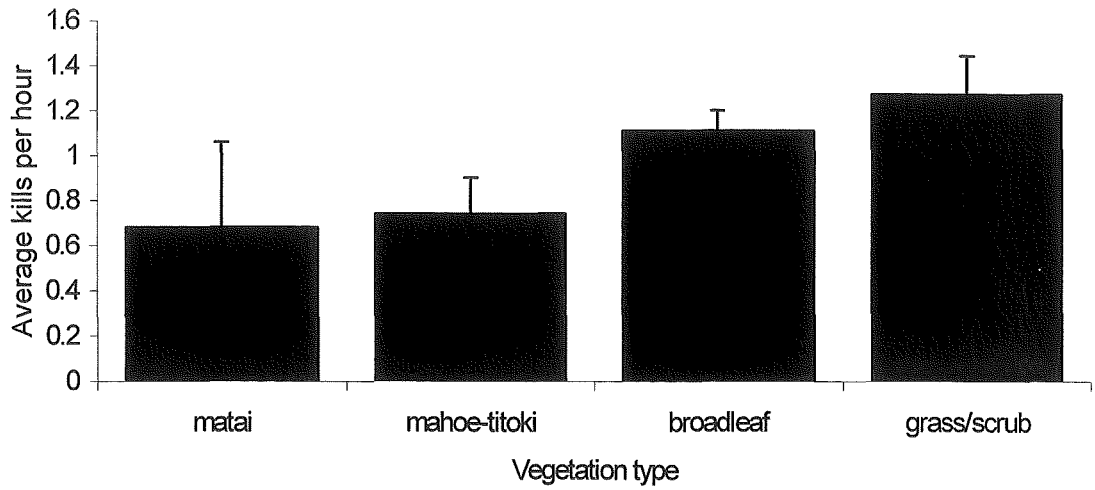


Figure 5.5 Vegetation type differences in the average number of kills per hunter hour (mean values ± 1 S.E.) at. Isolated Hill Scenic Reserve 2 December 1991 – 17 February 1997.

Effects of weather on average kill rates were also analysed (Fig. 5.6). However as was evident from analysis of the data and a t-test there were no statistically significant differences between wet or fine weather.

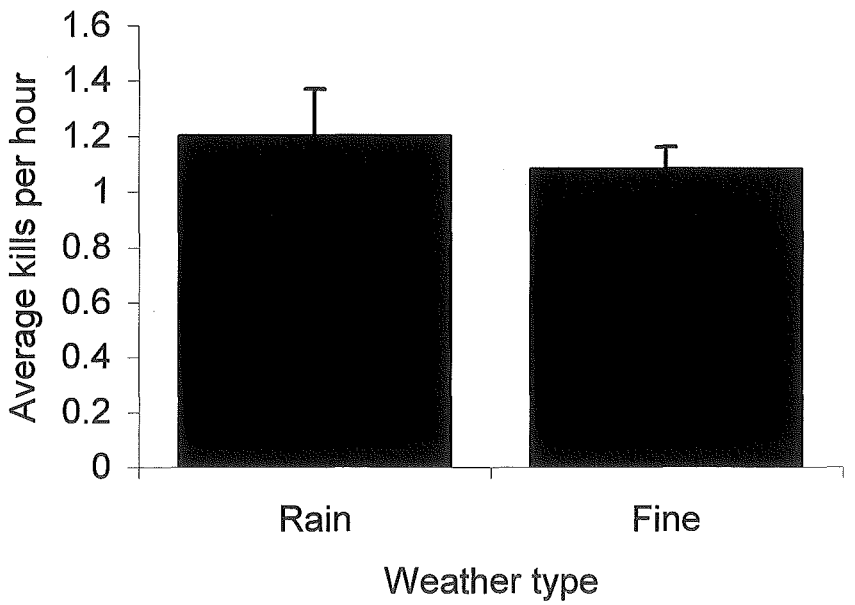


Figure 5.9 Weather differences in the average number of kills per hunter hour (mean values ± 1 S.E.) at Isolated Hill Scenic Reserve 2 December 1991 – 17 February 1997.

5.4 Discussion

5.4.1 Goat kills, hunting difficulty

Significant correlation was found between percentage allocation of kills across and pellet density data for habitats ($P < 0.05$). Percentage kills was not significantly correlated with direct observation of feral goat mobs ($P = 0.19$). In Hall's totara, improved grassland, mahoe-titoki, red beech, subalpine percentage of kills is close to the percentage of goat observations via direct or faecal observation. This indicates that hunters are killing animals in accordance with their habitat selection and utilisation.

When percentage of kills is compared to rank hunting difficulty (Fig 5.2) a strong relationship is observed if improved grassland and subalpine vegetation are removed from the analysis. Both of these vegetation types are on the edges of Isolated Hill Scenic Reserve and are utilised by pastoralists for sheep and cattle grazing. Thus, adjoining landowners control feral goats in these vegetation types to remove competition with stock.

Statistically significant differences were found between three different categories of hunters used by the Department of Conservation at Isolated Hill Scenic Reserve. Task Force Green hunters were found to be significantly more expensive than specialist casual staff. In itself this is not unusual as two fundamentally different groups of people are being compared. The Task Force Green people were long-term unemployed who were being helped back into the workforce. Conversely, the casual group consisted of contractors with many years of experience. A significant result is therefore unsurprising. The model presented in this study did not account for the subsidy that was paid to the Department of Conservation to employ Task Force Green staff. Potentially, given a 50% subsidy, Task Force Green staff would have been more in line with casual staff. Or would they have? Task Force Green staff had a mean cost per kill of $90.08, whereas casual staff had an average of $23.01, so even with a 50% subsidy casual staff returned a cost per kill that was 51% of the cost for Task Force Green Staff.

No significant results were found for the average number of kills per hour and season, or weather. This suggests that time of year and weather conditions do not affect kill rates in a significant manner. This seems counter-intuitive for weather, although feral goat mobs were observed to take cover from rain only during cold southerly weather

during the period of the study. Rain may serve to disguise the approach of hunters by reducing noise, and also by reducing hunter scent (W. Batchelor pers. comm.). Similar to season and weather the four habitats that were tested (matai, mahoe-titoki, broadleaf, and grass/scrubland) did not show any significant differences in average kills per hour.

5.4.2 The economics of animal control

The simple model of cost per kill (CPK) developed for the Isolated Hill Scenic Reserve data allows for incorporation of planning and operational costs into calculating the true costs per killed animal. Average number of kills per hour can be used as an indicator of encounter rate of feral goats. This suggests that as encounter rate drops operational costs increase dramatically. Cowan (1992) showed that costs for eradicating possums from Kapiti Island, a New Zealand nature reserve, rose from approximately $50 000 for the first 11 500 possums to $220 000 for the last 80 possums. Brennan (1992) in a study of feral goats at Dinner Creek (near Isolated Hill Scenic Reserve) found that costs rose as the encounter rate for feral goats dropped. Brennan found that 11 hours of hunting were able to remove 50% of the feral goat population (at a cost of approximately $50 per hr, hence $550). The remaining 50% of the population required 14 hours hunting to kill them all ($700).

Knowledge of habitat selection by feral goats could potentially have the direct effect of reducing costs per kill by increasing the average number of kills per hour hunting. Knowing where goats are within reserves (or are likely to be) allows the exploitation of the heterogeneity of a landscape, *i.e.* hunters can target areas that are most likely to have feral goats within them. However, given that at Isolated Hill hunters already appear to be allocating hunting effort (as shown by percentage distribution of kills) appropriately what difference can habitat selection knowledge make? Application could be found for new hunters who are operating in an area for the first time, or alternatively habitat selection knowledge could be used for performance monitoring of sub-contracted control operations.

Hone (1994) noted that a considerable range of data were needed to accurately analyse and model costs associated with vertebrate pest control. Quantification is needed of benefits, costs, and opportunity costs associated with specific control programmes. It is

these data that need to be assessed and collated for individual control programmes if we are to attempt to link economic models with models of population dynamics and resource change.

5.4.3 Linking habitat models and management: implications for conservation

Habitat selection models that provide information on the relationship between feral goats and parts of the landscapes in which they live can potentially benefit management of control operations. Within the system proposed by Parkes (1993) information about habitat selection could be initially incorporated at the level of individual operations (Fig. 5.10) but later could be used at strategic levels in setting conservation priorities and risk assessments. The release of the New Zealand Biodiversity Strategy (Anon, 1998) and the move within it to emphasise conservation on lands other than those administered by the Department of Conservation also creates a niche for the incorporation of habitat selection models. Feral goats do not observe cadastral boundaries and hence, are not only a pest on conservation lands. The primacy of the Biosecurity Act 1996 on non-conservation lands (as opposed to the Wild Animal Control Act 1977 on Conservation land) means that surveillance and monitoring of pest spread are legislated for. Specifically habitat selection models would help control programmes through their ability to provide a surveillance tool and a post-operational monitoring tool (Fig. 5.11).

If habitat selection models are to be used by managers they will need to be technically sound, well tested and properly applied (Toth and Baglien, 1986). Schamberger and O'Neill (1986) state that habitat models can incorporate the rigour of science into the realm of decision making. Habitat models are not models of carrying capacity, instead they attempt to quantify habitat in terms of its suitability to particular animal species. Habitat models act to focus attention on both the pest and the resource at the same time, thus allowing better management decisions.

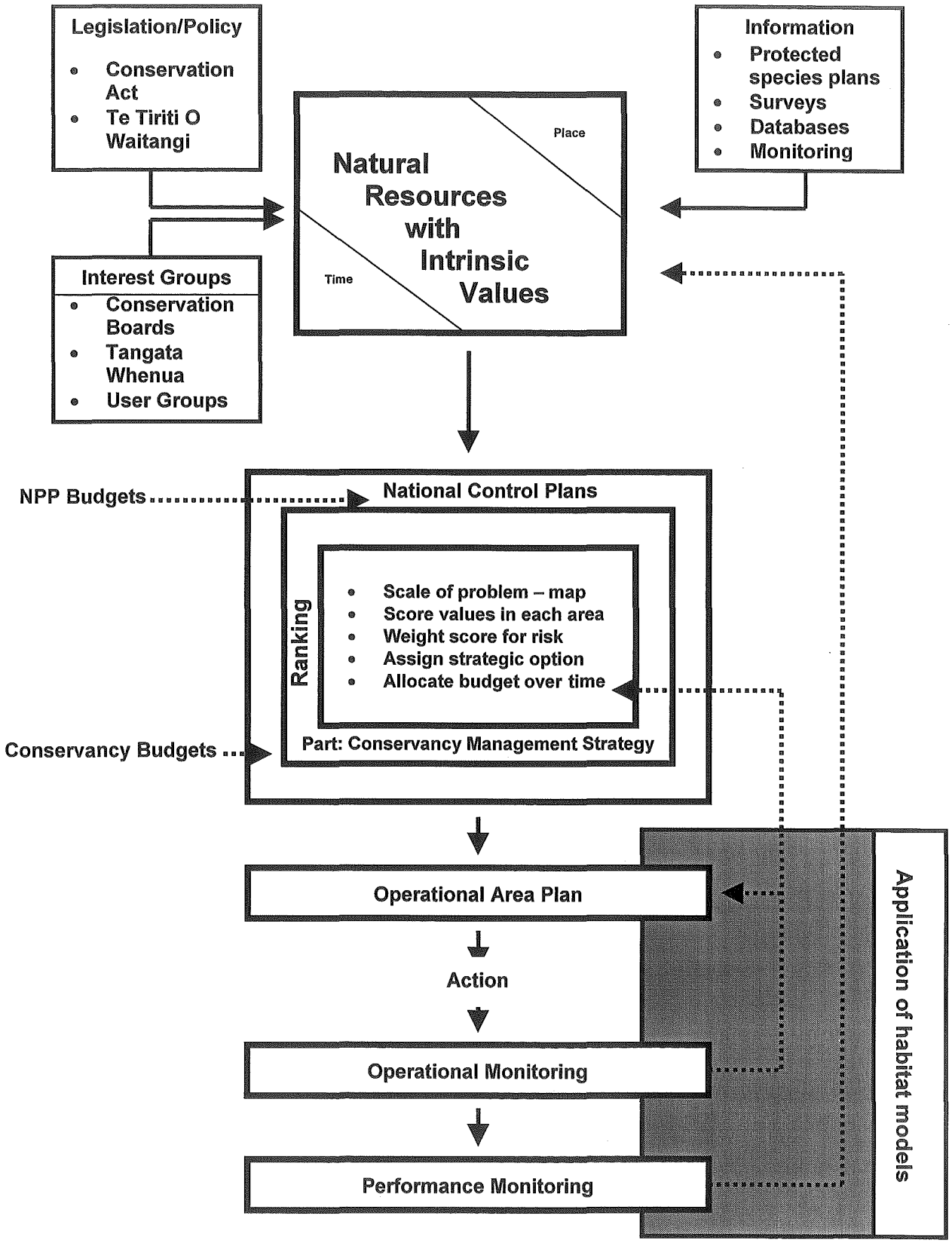


Figure 5.10 Schematic diagram indicating the potential for the inclusion of information derived from habitat selection studies of feral goats. Initially inclusion could be for specific operations, however potential exists to use habitat selection information at strategic levels (adapted from Parkes, 1993).

Application of habitat selection and use models to control programmes		
Planning phase	**Operational phase**	**Post-operational phase**
• Surveillance and monitoring • Identification of threat to particular biodiversity values through habitat selection • Planning of targetted control based on season • Facilitation of identification of bio-indicators	• Targetting of control to areas of preferred habitat and areas of known high density	• Monitoring of control outcomes via inspection of known preferred habitats • Monitoring of control via bio-indicators • Surveillance of preferred habitats in contiguous non-operational areas

Figure 5.11 Application of pest-habitat selection models to the process of wild animal control programmes.

5.5 Conclusions

This chapter has investigated aspects of the management of feral goats at Isolated Hill Scenic Reserve, and suggested how habitat selection models could be usefully integrated into operational programmes. Specifically this chapter has shown:

1. the distribution of kill locations in habitats is similar to data of pellet group densities for feral goats. Kill location distribution was not similar to direct observation of feral goat habitat selection at Isolated Hill Scenic Reserve;

2. perceived hunting difficulty is strongly correlated with distribution of kills. Habitats that were easiest to hunt were grassland or subalpine habitats. The most difficult habitats to hunt were red beech and bluffs and screes. If subalpine and improved grassland habitats are removed from the analysis, the greatest number of kills occur in habitats that are easiest to hunt;

3. hunter effectiveness varies significantly depending upon the category of hunter. Task Force Green hunters were significantly less efficient than casual hunters;

4. season, habitat, and weather did not significantly affect average kills per hour of feral goats at Isolated Hill Scenic Reserve. are apparent in the average number of kills per hour that can be achieved;

5. habitat selection and use models could be incorporated into operational control programmes so as to improve surveillance, targeting of habitats and post-operational auditing.

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Appendix 1 - Plant species botanical names, codes, and common names

Acaena anserinifolia	ACAESP	Bidibid
Aciphylla sp.	ACIPSP	Spaniard
Agrostis capillaris	AGRCAP	Browntop
Agrostis stolonifera	AGRSTO	Creeping bent
Alectryon excelsus	ALEEXC	Titoki
Anthoxanthum odoratum	ANTODO	Sweet vernal
Aristotelia serrat	ARISER	Wineberry
Asplenium sp.	ASP SP	
Astelia nervosa	ASTNER	
Blechnum sp.	BLECSP	
Blechnum discolor	BLEDIS	Crown fern
Blechnum penna-marina	BLEPEN	Little hard fern
Bromus sp.	BROMSP	
Cardamine sp.	CARDSP	bittercress
Carpodetus serratus	CARSER	Putaputaweta
Cassinia leptophylla	CASLEP	Cassinia
Celmisia sp.	CELMSP	
Chionochloa sp.	CHINSP	Snow tussock
Cirsium sp.	CIRSSP	Thistle
Clematis sp.	CLEM S	Clematis
Coprosma areolata	COPARE	
Coprosma colensoi	COPCOL	
Coprosma crassifolia	COPCRA	
Coprosma foetidissima	COPFOE	Stinkwood
Coprosma grandifolia	COPGRA	
Coprosma linariifolia	COPLIN	
Coprosma lucida	COPLUC	Shiny karamu
Coprosma microphylla	COPMIC	
Coprosma parviflora	COPPAR	

Coprosma propinqua	COPPRO	Mingimingi
Coprosma pseudocuneata	COPPSE	
Coprosma sp.	COPR SP	
Coprosma rhamnoides	COPRHA	
Coprosma robusta	COPROB	Karamu
Coprosma rotundifolia	COPROT	
Coriaria arborea	CORARB	Tutu
Cordyline australis	CORAUS	Cabbage tree
Corokia cotoneaster	CORCOT	
Cortaderia sp.	CORTSP	Toetoe
Cyathea dealbata	CYADEA	Silver fern
Cyathea smithii	CYASMI	Soft tree fern
Cyathodes fasciculata	CYAFAS	
Cyathodes fraseri	CYAFRA	
Cyathodes juniperina	CYAJUN	
Dactylis glomerata	DACGLO	Cocksfoot
Digitalis purpurea	DIGPUR	Foxglove
Discaria toumatou	DISTOU	Matagouri
Dodonaea viscosa	DODVIS	Akeake
Echium vulgare	ECHVUL	Vipers bugloss
Elaeocarpus hookerianus	ELAHOO	Pokaka
Fuchsia excorticata	FUCEXC	Fuchsia
Gaultheria spp.	GAULSP	Snowberry
Gentiana astonii	GENAST	
Geranium spp.	GER SP	
Griselinia littoralis	GRILIT	Broadleaf
Helichrysum aggregatum	HELAGG	
Helichrysum belledioides	HELBEL	
Hieracium spp.	HIER S	Hieracium
Holcus lanatus	HOLLAN	Yorkshire fog
Hydrocotyle spp.	HYDRSP	Pennywort
Hypolepis spp.	HYPOSP	
Kunzea ericoides	KUNERI	Kanuka
Leptospermum scoparium	LEPSCO	Manuka

Leucopogon colensoi	LEUCOL	Heath
Libertia ixioides	LIBIXI	Native iris
Linum cartharticum	LINCAR	Purging flax
Lolium perenne	LOLPER	Perennial ryegrass
Lycopodium volubile	LYCVOL	Clubmoss
Macropiper excelsum	MACEXC	Kawakawa
Melicytus alpinus	MELALP	Porcupine shrub
Melicytus ramiflorus	MELRAM	Mahoe
Microlaena avenacea	MICAVE	Bush rice grass
Moss spp.	MOSS	
Muehlenbeckia spp.	MUEHSP	Pohuehue
Mycelis muralis	MYCMUR	Wall lettuce
Myoporum laetum	MYOLAE	Ngaio
Myrsine australis	MYRAUS	Red mapau
Myrsine divaricata	MYRDIV	Weeping mapou
Nertera depressa	NERDEP	
Nothofagus fusca	NOTFUS	Red beech
Nothofagus solandri	NOTSOL	Mountain beech
Olearia paniculata	OLEPAN	Akiraho
Pachystegia insignis	PACINS	Marlborough rock daisy
Parsonsia heterophylla	PARHET	New Zealand jasmine
Pellaea rotundifolia	PELROT	
Pennantia corymbosa	PENCOR	Kaikomako
Phormium spp.	PHOR S	Flax
Phymatosorus diversifolium	PHYDIV	Devils hounds tongue
Pimelea spp.	PIMESP	
Pittosporum eugenioides	PITEUG	Lemonwood
Pittosporum tenuifolium	PITTEN	Kohuhu
Plantago spp.	PLAN S	Plantain
Poa spp.	POA SP	
Poa cita	POACIT	Silver tussock
Podocarpus hallii	PODHAL	Hall's totara
Podocarpus totara	PODTOT	Totara
Polystichum vestitum	POLVES	Shield fern

Prumnopitys ferruginea	PRUFER	Miro
Prumnopitys taxifolia	PRUTAX	Matai
Pseudopanax arboreus	PSEARB	Five-finger
Pseudopanax crassifolium	PSECRA	Lancewood
Pseudowintera colorata	PSECOL	Horopito
Pteridium esculentum	PTEESC	Bracken
Pyrrosia spp.	PYRRSP	Leather leaf fern
Ranunculus hirtus	RANHIR	Hairy buttercup
Rosa rubiginosa	ROSRUB	Sweet briar
Rubus cissioides	RUBCIS	Bush lawyer
Rubus squarrosa	RUBSQU	Bush lawyer
Rumex acetosella	RUMACE	Sheeps sorrel
Schoenus sp.	SCHOSP	
Senecio jacobea	SENJAC	Ragwort
Senecio monroi	SENMON	Marlborough rock coral
Sophora microphylla	SOPMIC	Kowhai
Stellaria sp.	STELSP	Chickweed
Taraxacum sp.	TAR SP	Dandelion
Trifolium repens	TRIREP	White clover
Tupeia antarctica	TUPANT	Mistletoe
Uncinia sp.	UNCISP	"Bastard grass"
Urtica ferox	URTFER	Ongaonga
Urtica incisa	URTINC	Stinging nettle
Verbascum thapsus	VERTHA	Woolly mullen
Viola sp.	VIOLSP	
Wahlenbergia albo-marginata	WAHALB	

Appendix 2 - Diversity Indices

Berger-Parker Diversity Index

$$d = \frac{N_{\max}}{N}$$

Where: N_{max} = number of individuals in the most abundant taxon
N = total number of individuals

Margalef's Diversity Index

$$d = \frac{(S-1)}{\ln N}$$

Where: S = number of taxa
N = number of individuals

Taxonomic richness

A simple count of the number of taxa present in a community.

Notes from Magurran (1988).

Two components to diversity – the species presence and absence, and its relative abundance. There are three broad types of diversity index:

1. Species richness indices (alpha diversity, and Margalefs index);
2. Species abundance models;
3. And indices based on the proportional abundance of species.

Species abundance data are generally examined in terms of 4 main models. These are the log normal distribution, the geometric series, the logarithmic series and the broken stick model. These can be though of as representing relative niche space. Hence evenness is high in the broken stick model and low in the geometric series.

The Berger – Parker index is often used in the form 1/d. Magurran also comments on the use of cover as a proxy for abundance. Magurran notes that the concept of cover is not easily transportable across species barriers. Where cover scales are used (for example Daubenmire scale) the lack of linear correlation with abundance makes them less useful in indices.

Appendix 3 – Climate at Isolated Hill Scenic Reserve and Black Angel Creek

Introduction

Climate was measured at Isolated Hill Scenic Reserve and Black Angel Creek using two datalogger stations. Variables were measured for two reasons:

1. to ensure that both areas experienced similar weather conditions
2. to provide data for habitat modelling.

Methods

Three climatic factors were recorded at Isolated Hill Scenic Reserve and Black Angel Creek. Campbell CR21X dataloggers were used to record rainfall, temperature, and wind direction at two locations within the study areas. One datalogger was placed in the Black Angel Creek area at an altitude of 780 m; the second datalogger was placed on White Spurs - a ridgeline overlooking the front face of Isolated Hill - at an altitude of 700 m.

The dataloggers were housed within standard Meteorological Service Stephenson screens. Each climate station had four single ended thermocouples to record temperature, one 1 mm tipping rain-bucket, and one wind vane calibrated to record wind direction for 24 hour periods in each of eight compass sectors. The wind vane was mounted on a pole at 1.4 m in height, while the rain-bucket was mounted on the top of the Stephenson screen (approximately 30 cm in height).

A 12 volt sealed battery which was connected to a Gallagher solar panel powered the dataloggers. A data storage module was also included within the system to insure against sudden power loss to the main data storage area in the Campbell CR21X datalogger (the value of this system was shown in the loss of solar panel power to the Black Angel Creek

unit). The climate stations were placed within an electrified exclosure to guard against stock, feral pig, and feral goat interference.

Further climate measurements were gained from Mr D. Buick in the form of daily rainfall records from March 1964 through to December 1996 for Blue Mountain Station.

Observations

Battery Voltage

From a technical perspective the connection of solar panels to the datalogger batteries meant that batteries did not need to be regularly changed. The datalogger at Black Angel Creek (which initially was not connected to a solar panel) recorded a dramatic change in battery voltage after attachment of a solar panel (Fig. A3.1). From early January 1997 battery voltage at Black Angel Creek was recorded to drop (Fig. A3.1), presumably due to connections between the solar panel and the battery breaking. This may have been due to stock interference (despite the electric fences sheep interfered with the datalogger at Black Angel Creek, and pigs damaged the site at Isolated Hill) or through the action of wind.

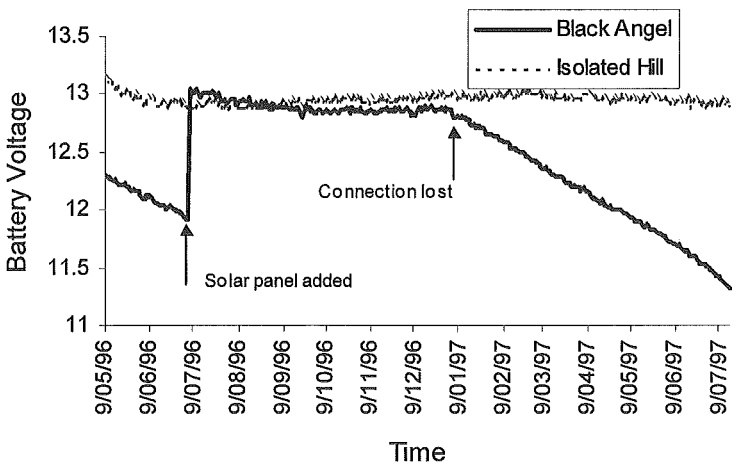

Figure A3.1 Mean daily battery voltage for the two climate datalogger sites at Isolated Hill Scenic Reserve and Black Angel Creek. Solar panels were attached to batteries at both sites, at Isolated Hill for the entire period, and at Black Angel Creek as indicated.

Temperature

Temperature data were recorded at both sites (Fig. A3.2) and were compared to ensure that both areas experienced similar temperatures. Pearson correlation analysis revealed coefficients of 0.87 ($P<0.001$) for maximum temperatures and 0.95 ($P<0.001$) for

minimum temperatures. Temperature data were also compared with data collected from three other sites in the Marlborough-Kaikoura area, Kaikoura, Grassmere, and Blenheim. Temperature data were compared using simple scatterplot matrices for maximum (Fig. A3.3), average (Fig. A3.4) and minimum (Figure A3.5) air temperatures. Relationships

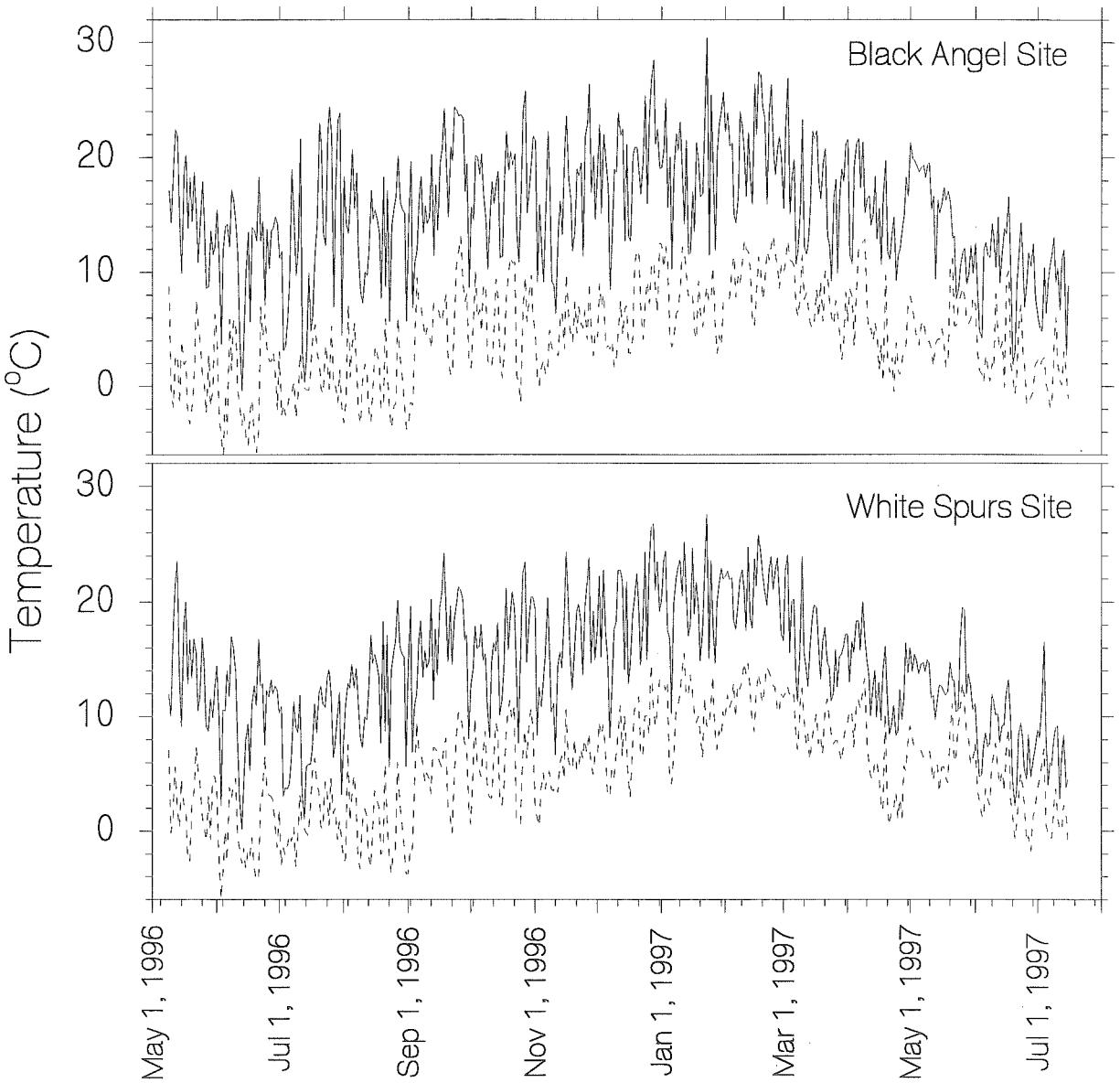

Figure A3.2 Temperature data from Isolated Hill Scenic Reserve and Black Angel Creek datalogger sites. Maximum temperature and minimum air temperature are recorded (max -, min - -).

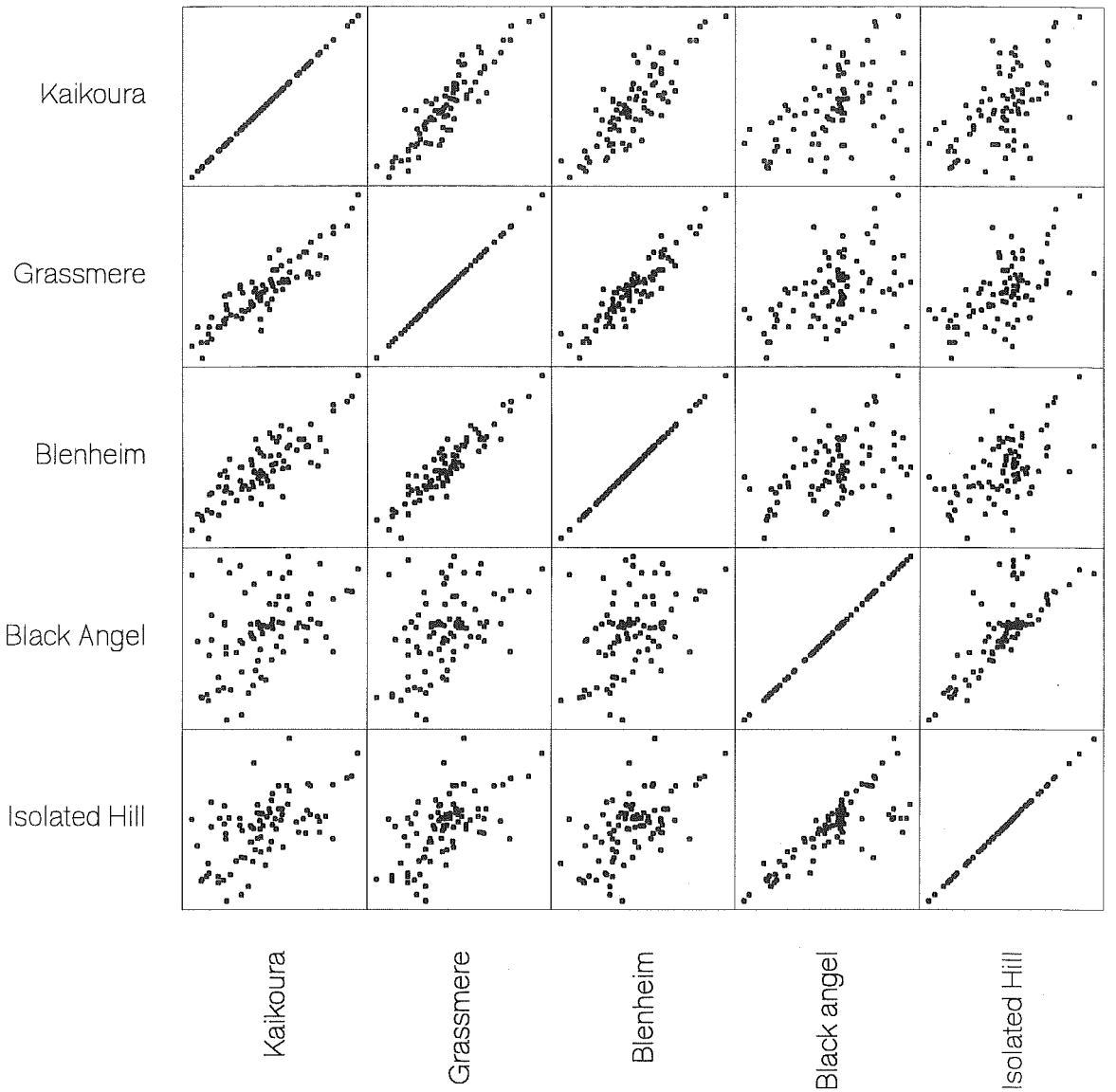

Figure A3.3 Matrix correlation of maximum temperature recorded at five sites in Southern Marlborough during the period 9 May 1996 – 30 December 1996. Kaikoura is at an altitude of 108 m, Grassmere an altitude of 2 m, Blenheim an altitude of 27 m, Black Angel is at an altitude of 780 m, Isolated Hill an altitude of 700 m..

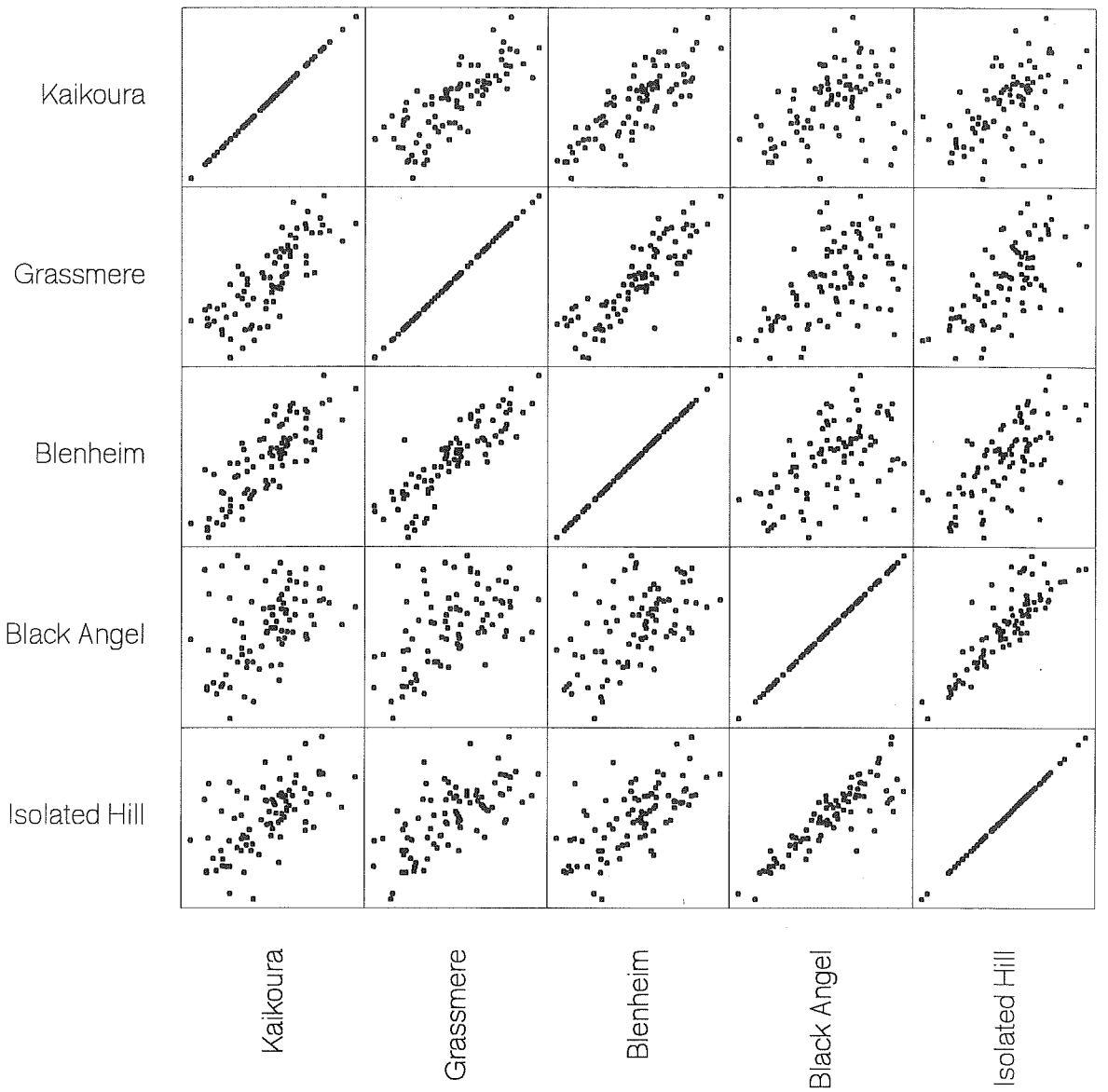

Figure A3.4 Matrix correlation of average temperature recorded at five sites in Southern Marlborough during the period 9 May 1996 – 30 December 1996. Kaikoura is at an altitude of 108 m, Grassmere an altitude of 2 m, Blenheim an altitude of 27 m, Isolated Hill an altitude of 700 m.

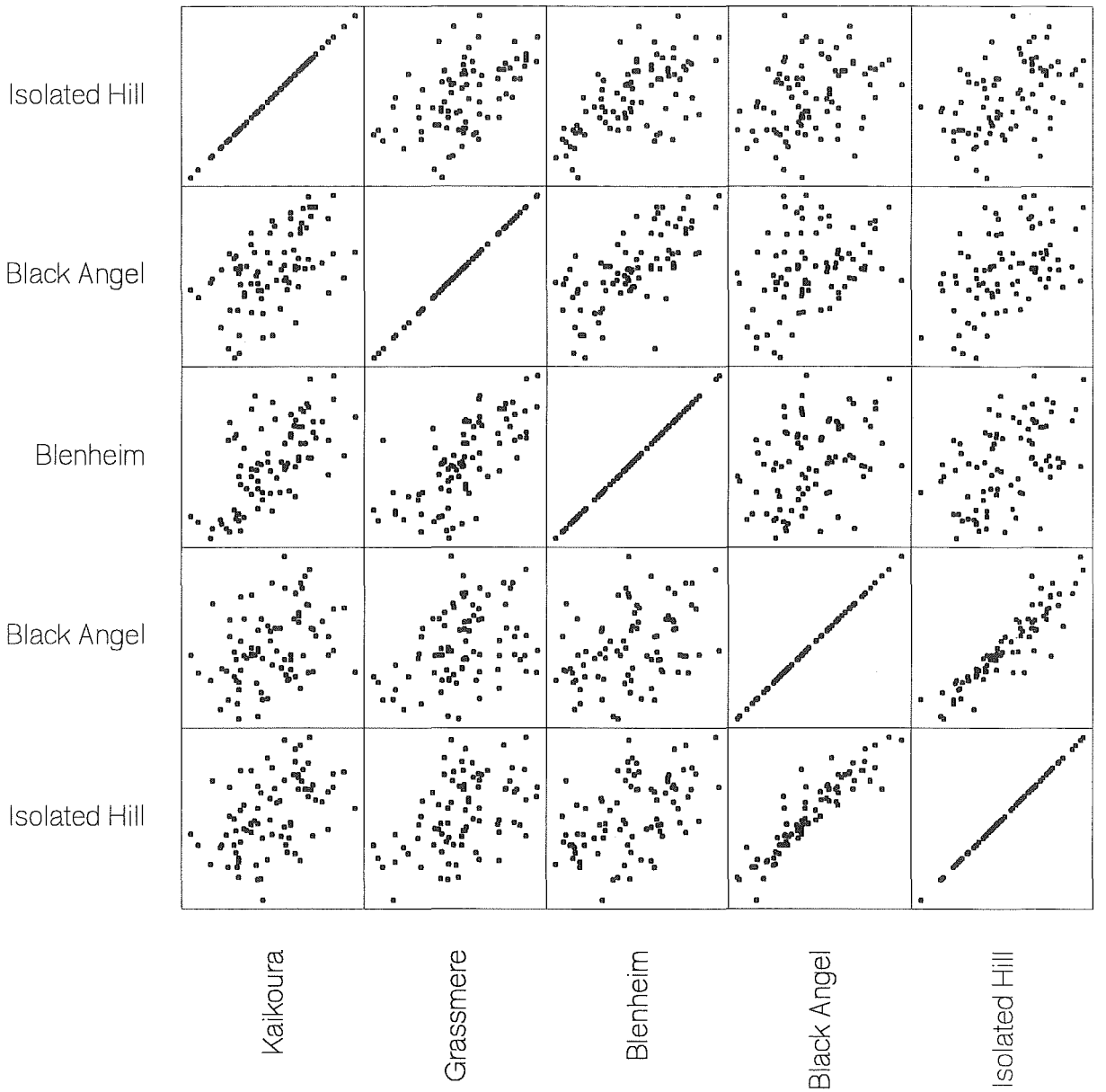

Figure A3.5 Matrix correlation of minimum temperature recorded at five sites in Southern Marlborough during the period 9 May 1996 – 30 December 1996. Kaikoura is at an altitude of 108 m, Grassmere an altitude of 2 m, Blenheim an altitude of 27 m, Isolated Hill an altitude of 700 m.

between the study sites and the three other sites were poor, which reflects the coastal nature of the three non-study sites. For future studies of higher inland sites temperature data from farms (where available) would be more appropriate for calculating unknown temperatures.

Rainfall

Rainfall was recorded at both datalogger sites and was also collected at from records held at Blue Mountain Station. Rainfall was compared for the study period at all three sites, and strong relationships were revealed (Figs. A3.6, A3.7, A3.8, and A3.9).

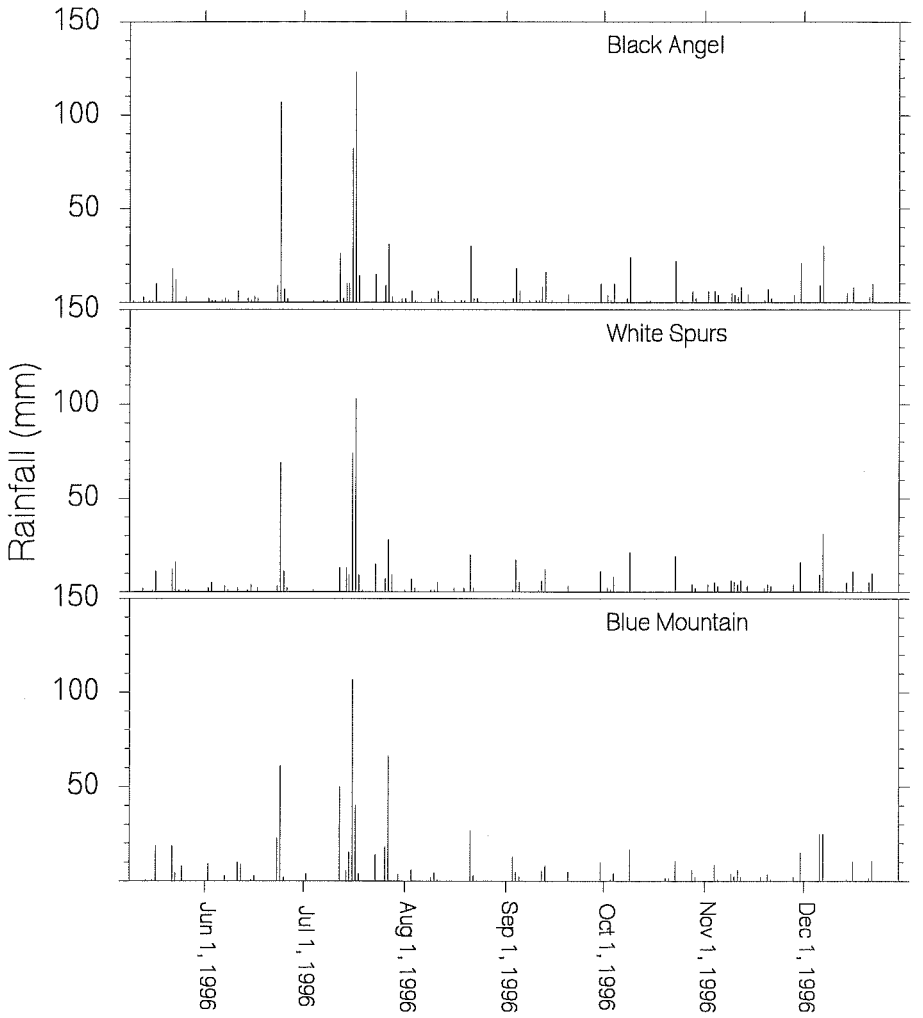

Figure A3.6 Rainfall data for Black Angel Creek and Isolated Hill Scenic Reserve (White spurs) datalogger sites, and Blue Mountain Station rainfall recorder.

Regression plots were used to indicate relationship between differing sites. A strong relationship was recorded for the two datalogger sites ($r^2 = 0.97$) (Fig. II.7), however, rainfall records at Blue Mountain Station were less able to predict rainfall at Black Angel Creek ($r^2 = 0.21$) (Fig. II.8), and Isolated Hill ($r^2 = 0.25$) (Fig. II.9).

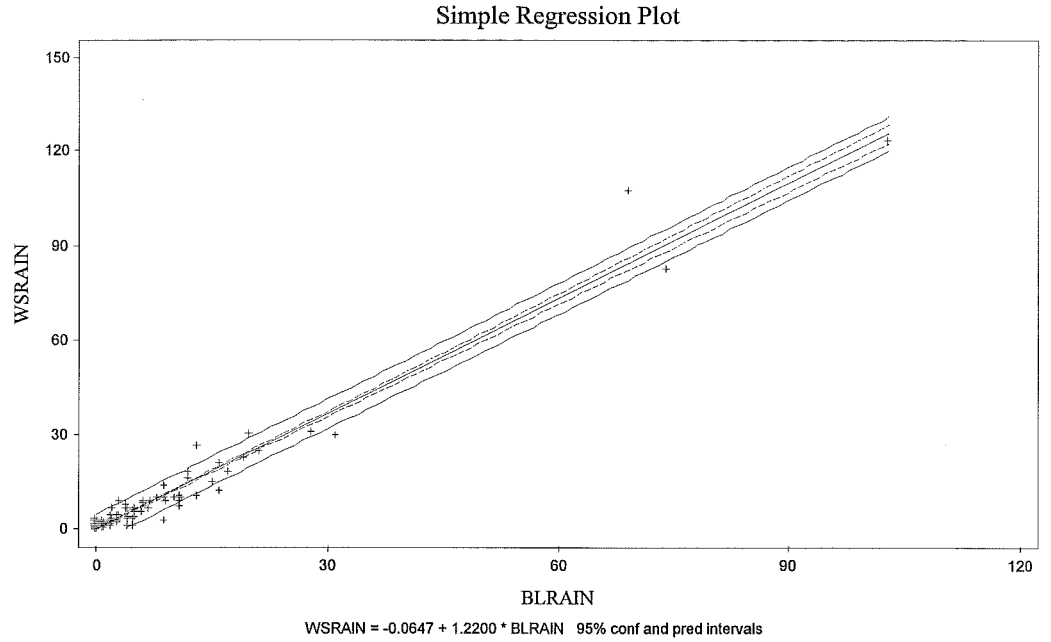

Figure A3.7 Regression plot between Black Angel Creek rainfall and the Isolated Hill Scenic Reserve rainfall recorder site (r^2 for the linear regression is 0.97).

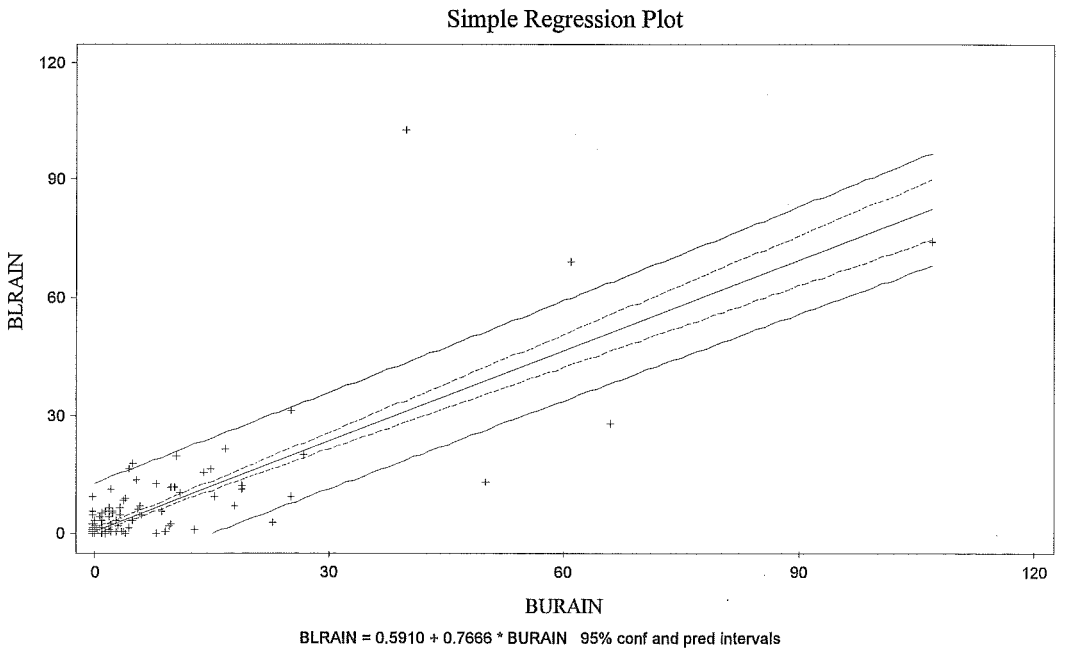

Figure A3.8 Regression plot showing the relationship between rainfall recorded at Blue Mountain station and its ability to predict rainfall in Black Angel Creek recorder site (r^2=0.21).

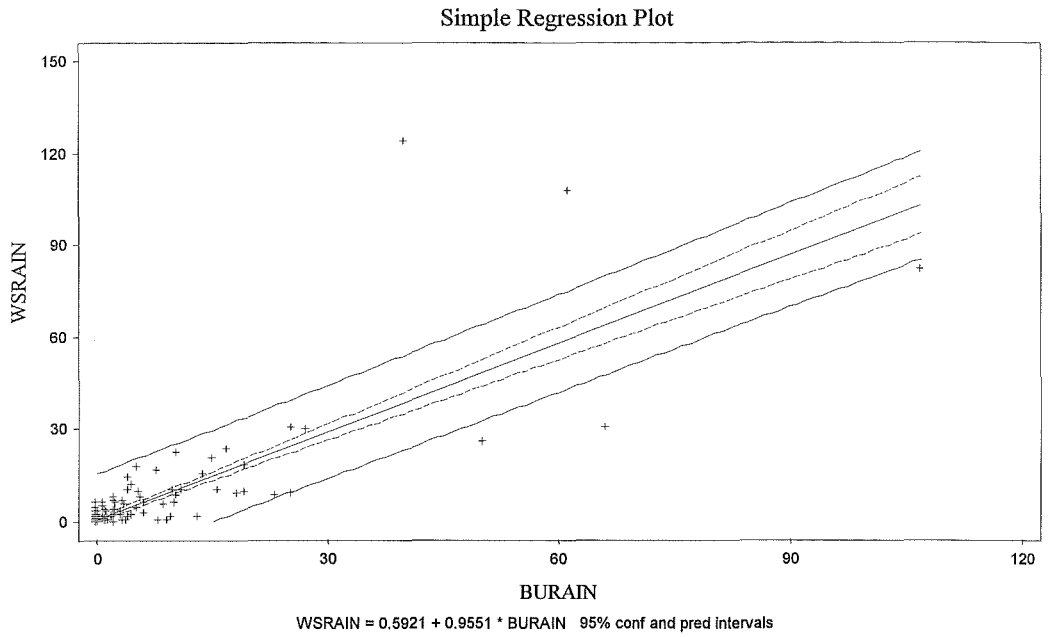

Figure A3.9 Regression plot showing the relationship between rainfall recorded at Blue mountain station and its ability to predict rainfall at the Isolated Hill Scenic Reserve recorder site (r^2=0.25).

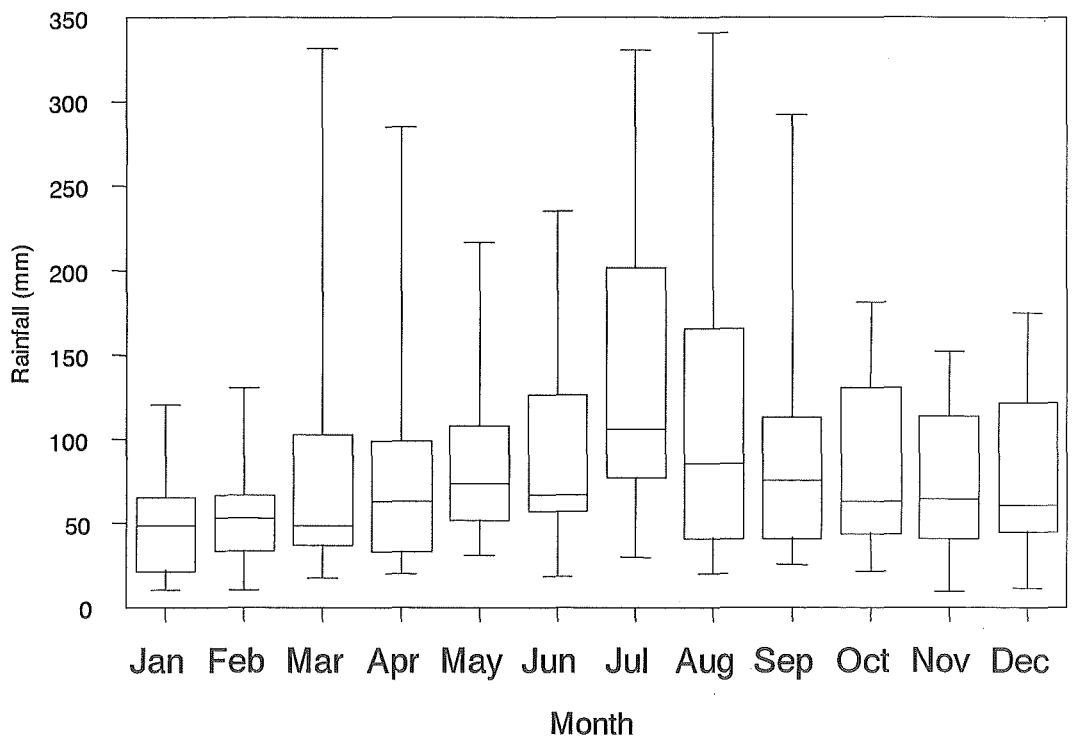

Figure A3.10 Tukey Box plot of monthly rainfall data for Blue Mountain Station 1964-1996. Median, interquartile range, and 95% confidence intervals are displayed.

Rainfall records at Blue Mountain Station were also collated (Table A3.1) so monthly rainfall statistics could be calculated (Fig. A3.10). Two clear periods are recognisable for annual monthly rainfall, a drier period of October – February, and a wetter period from March – September.

Table A3.1 Monthly and annual rainfall data for Blue Mountain Station 1964 - 1996.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
1996	15.50	93.00	37.50	48.00	55.50	118.50	335.50	45.50	49.00	40.50	44.00	132.00	1014.50
1995	34.50	53.00	102.50	28.50	37.00	60.50	278.00	28.00	91.50	45.50	83.50	10.50	853.00
1994	34.50	53.00	102.50	28.50	37.00	60.50	278.00	28.00	91.50	45.50	83.50	10.50	853.00
1993	49.50	89.50	48.00	48.50	88.50	92.00	39.00	19.50	127.50	13.50	136.50	247.00	999.00
1992	48.50	62.50	27.00	17.50	145.00	55.00	203.00	93.00	160.00	182.50	35.50	66.50	1096.00
1991	60.00	64.00	16.50	150.50	10.00	116.00	78.50	60.50	99.00	24.00	130.00	101.00	910.00
1990	38.00	11.00	43.50	50.00	114.50	16.50	157.50	284.00	116.50	63.00	150.00	27.50	1072.00
1989	93.50	65.50	38.00	25.50	65.00	128.50	29.50	186.50	312.00	172.00	72.50	48.00	1236.50
1988	12.50	35.00	71.00	19.00	53.00	64.50	215.00	72.50	35.00	42.00	65.00	51.50	736.00
1987	3.00	58.00	298.50	97.50	80.50	61.00	213.00	71.00	34.00	77.50	137.50	105.00	1236.50
1986	59.00	180.50	140.00	35.00	89.50	50.00	81.00	386.00	104.00	69.00	56.50	36.50	1287.00
1985	122.00	72.50	54.50	63.00	64.00	116.50	307.00	61.00	76.00	57.00	127.00	171.00	1291.50
1984	21.50	102.50	52.50	24.00	98.50	29.50	77.50	28.50	65.50	45.50	41.50	130.00	717.00
1983	15.50	17.00	47.00	85.00	62.50	74.50	99.50	25.50	62.50	163.50	59.50	95.50	807.50
1982	20.00	54.50	36.00	93.50	34.00	236.00	81.50	22.00	66.50	128.00	56.50	61.00	889.50
1981	10.00	10.00	47.00	59.50	220.50	137.50	73.50	154.00	28.50	142.50	116.50	45.50	1045.00
1980	58.50	73.00	337.50	294.00	30.50	227.50	194.00	80.50	42.50	71.00	112.50	146.50	1668.00
1979	16.50	64.50	484.50	25.00	105.50	60.00	105.50	351.00	33.50	92.50	42.50	142.00	1523.00
1978	22.00	14.50	39.50	340.00	98.00	331.50	334.50	145.00	95.00	70.00	27.50	49.50	1567.00
1977	108.00	46.00	22.50	80.50	82.50	144.50	201.50	179.50	134.00	104.00	26.50	73.50	1203.00
1976	97.00	135.50	34.00	50.50	41.00	45.00	149.50	160.50	186.00	63.00	39.00	143.00	1144.00
1975	112.50	67.00	236.00	95.50	55.00	228.50	26.00	86.00	48.50	141.00	106.50	48.00	1250.50
1974	56.00	43.00	89.50	230.50	121.50	66.50	143.00	147.50	310.50	139.00	6.50	26.00	1379.50
1973	55.50	23.00	46.25	24.25	69.50	37.50	74.00	75.50	70.00	39.00	64.00	60.50	639.00
1972	29.97	28.96	65.02	114.05	191.52	61.21	72.39	85.34	13.97	85.60	10.67	43.94	802.64
1971	165.86	45.97	35.81	43.94	170.94	66.55	86.61	198.63	27.18	227.58	85.34	15.75	1170.18
1970	39.37	5.33	192.53	78.23	193.29	59.69	79.50	119.38	125.98	54.61	16.26	51.82	1016.00
1969	31.75	37.34	2.54	121.41	73.15	32.51	30.23	13.72	111.76	44.45	165.61	66.04	730.50
1968	80.77	41.40	48.51	138.94	105.16	183.39	161.80	47.75	75.18	150.37	9.14	118.87	1161.29
1967	58.42	66.55	54.61	72.64	37.59	15.49	43.94	251.21	55.37	35.56	152.65	19.05	863.09
1966	111.00	49.53	78.99	80.52	328.17	57.91	188.72	154.69	77.72	48.26	48.26	175.26	1399.03
1965	42.93	26.16	125.48	101.85	62.48	73.41	100.84	222.00	24.89	21.84	59.94	47.24	909.07
1964			33.78	38.35	48.51	125.73	124.46	24.89	37.08	21.08	71.12	52.83	577.85
Average	53.86	55.91	93.61	84.96	93.01	98.00	141.32	118.44	90.55	82.44	73.92	79.36	

Wind direction

Wind direction was also recorded at both sites (Fig A3.11). Because of the division of the wind direction into quarters wind direction records were very similar. Some difficulty was experienced during periods of no or low wind when the wind vane instrument would simply stop in position. Wind direction proportions were dominated by morning and afternoon wind, which tended to follow the topography of the areas in which the dataloggers were placed.

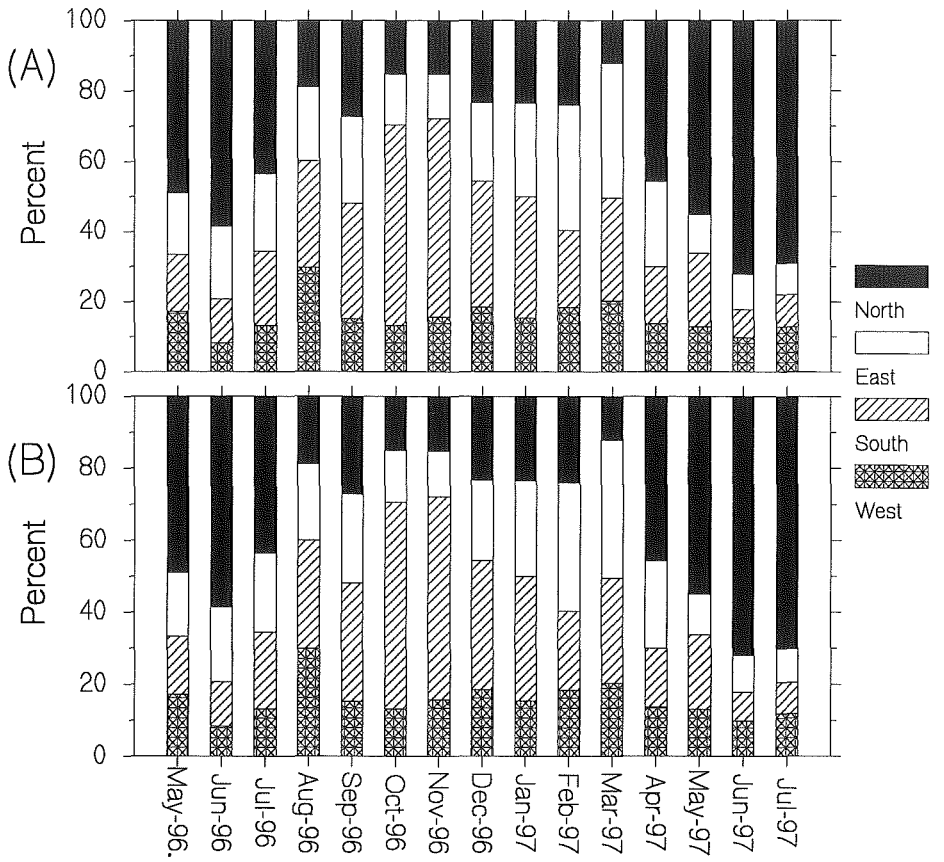

Figure A3.11 Monthly proportional wind directions for Black Angel Creek (A), and Isolated Hill Scenic Reserve (B) sites May 1996 – July 1997.

Conclusions

The climate data showed that the two datalogger sites received comparable weather during the duration of the recorded period. Further it was shown that rainfall was similar to that experienced at Blue Mounatin Station. However the data showed that study site temperatures were not weel predicted by temperature data for the three climate stations at Blenheim, Grassmere, and Kaikoura.

Plate A3.1 Climate datalogger station at Black Angel Creek, Blue Mountain Station.

Plate A3.2 Climate datalogger station at White Spurs, Isolated Hill Scenic Reserve.